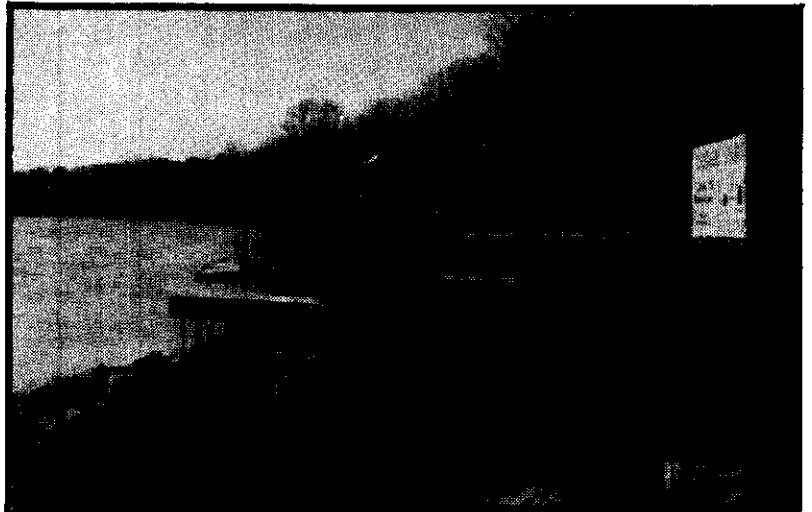

INVESTIGATION OF CHANNEL DEGRADATION 1991 UPDATE

MISSOURI RIVER GAVINS POINT DAM TO PLATTE RIVER CONFLUENCE



**US Army Corps
of Engineers**
Omaha District

INVESTIGATION OF CHANNEL DEGRADATION

1991 UPDATE

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CORPS OF ENGINEERS
OMAHA DISTRICT, ENGINEERING DIVISION

AUGUST 1991

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I. INTRODUCTION

1. **PURPOSE.** This report is the fifth in a series of updates to Volume IV, Supporting Technical Report, Missouri River Degradation. Volume IV is a part of the August 1981 Review Report of the Water and Related Land Resources Management Study for Metropolitan Sioux City and Missouri River Iowa, Nebraska, and South Dakota. This report, along with future updates, will provide the information necessary for proper management of the Missouri River in reference to degradation.

2. **SCOPE.** This report incorporates water surface profile and hydrographic survey data from the 1989 and 1990 water years for the purpose of updating the existing studies. Analyses of the historical trends, groundwater and oxbow relationships, and degradation trends are continued from the main report and the 1983, 1985, 1987, and 1989 updates. In addition, a 1987 analysis of the impacts on tributaries of the Missouri River from degradation is summarized. The study reach extends from Gavins Point Dam to the Platte River confluence.

3. **AUTHORITY.** The Omaha District operates and maintains a navigation project from Sioux City, Iowa to Rulo, Nebraska under the authority of the River and Harbor Act of 1945.

4. **RUNOFF BACKGROUND.** The runoff upstream from Sioux City, adjusted to the 1949 level of depletion for the calendar year 1989, was 17.7 million acre-feet (MAF), 7.3 MAF below normal and the 15th lowest runoff since 1898. Runoff in 1989 was only 71 percent of normal due primarily to low mountain snowpack and extremely dry subsoil moisture conditions throughout most of the upper basin. Although the 1989 runoff above Sioux City was only 71 percent of normal, the distribution in the six river reaches above Sioux City varied greatly from 133 percent of normal above Gavins Point to 66 and 85 percent of normal in the reaches above Garrison and Fort Peck, respectively. The Oahe reach experienced only 51 percent of normal runoff which was much above the 17 percent experienced in 1988. Drought conditions improved somewhat in the spring of 1990. The majority of the basin received near normal precipitation during March through May 1990. The total runoff from August 1989 to July 1990 upstream from Sioux City was 18.2 MAF, 3.5 MAF below normal. Overall, climatic conditions in many parts of the Missouri River Basin were comparable to the severe drought years of 1934 and 1936.

II. HISTORICAL TRENDS

1. **ADJUSTED WATER SURFACE PROFILES AND WATER SURFACE DECLINE/RISE.** Water surface profiles for 1989 and 1990 were developed for comparison with profiles of earlier years. As

stated in the main report, the water surface profiles extend from Yankton, South Dakota to the Platte River's confluence with the Missouri River. The 1989 and 1990 profile data were obtained 24-25 July 1989 with a Gavins Point average daily discharge of 25,200 cfs, and 5-6 September 1990 with a Gavins Point average daily discharge of 30,600 cfs. To maintain consistency with the main report, each profile was adjusted to represent a discharge of 30,000 cfs at Sioux City, Iowa. This adjustment was accomplished by determining the difference between the actual water surface profile elevation and the summer discharge-rating curve elevation for the design discharge at each of the USGS gaging stations at Yankton, Sioux City, Decatur, Omaha, and Nebraska City. The actual profile, between two of the gaging stations, was adjusted by prorating the difference at the USGS gages throughout the reach.

1.1 Figures 1-S5 through 4-S5 are plots of the water surface profiles of the study reach for the years 1957, 1977, 1988, 1989, and 1990. Comparison of the 1988, 1989 and 1990 profiles indicates that very little change has occurred in the navigation reach above Omaha over the last several years. A slight rise in water surface elevation is evident in 1988 between river miles 615 and 600. Figure 3-S5 shows an abrupt change in the water surface slope of the 1957 profile near river mile 642. This corresponds to the location of the DeSoto Bend Cutoff which was completed in 1960. This anomaly results from plotting the 1957 water surface data with the 1960 river mileage.

1.2 The data from the 1989 and 1990 adjusted water surface profiles were compared by developing decline/rise plots as presented in the main report. Figures 5-S5 through 8-S5 compare water surface differences for the years 1977, 1989, and 1990 in various combinations.

1.3 Figure 5-S5 (1977-1989) shows a general decline in water surface elevation from Gavins Point Dam to river mile 610. The reach from river mile 780 to 755 deviates from this general decline somewhat with an average decline of only 0.5 feet. This area corresponds with the upper extent of the Kensler's Bend Project. The maximum decline, 2.9 feet, is at river mile 810.

1.4 Figure 6-S5 (1977-1990) shows a trend similar to Figure 5-S5. A maximum decline of 3.3 feet occurs at river mile 810. A small rise of 0.2 feet is noted at river mile 755.

1.5 Figure 7-S5 (1989-1990) shows that little change has occurred throughout the study reach between 1989 and 1990. The maximum change in water surface elevation during this time period was a rise of 0.6 feet at river miles 750, 665 and 645.

1.6 Figure 8-S5 shows plots of water surface declines and rises for the years 1957 to 1977 and 1957 to 1990. These

plots show a general decline in water surface elevation from Gavins Point to river mile 642 (Desoto Bend). The maximum decline occurs at river mile 810 at 9.5 feet. The study reach downstream of river mile 642 has exhibited a rise of less than 2 feet.

2. STAGE-DISCHARGE. Stage trend curves for USGS gaging stations at Yankton, Sioux City, Decatur, and Omaha were developed for a discharge of 30,000 cfs at Sioux City for this update. Figure 9-S5 shows updated curves which include the 1989 and 1990 data. Water surface elevations at each gage for the given discharge were determined by developing rating curves at each gage location for a given year. Nonlinear regression analysis was used to fit curves to the stage-discharge data.

2.1 At Yankton, the decline in elevation continues to occur at a near constant rate. Over the past ten years, an average rate of decline of 0.2 foot per year has been observed. This rate has been slightly more than the predicted rate (see par. 3, section VI of this report).

2.2 At Sioux City, the declining trend exhibited since 1983 continued into 1987. However, from 1987 to 1990, this trend was reversed and rises of 0.4, 0.4 and 0.1 foot were noted in years 1988, 1989, and 1990, respectively. This rise falls within the predicted range for this gage location. Future updates may show the sudden rise to be an anomaly.

2.3 At Decatur, the stage has continued to decline over the past 8 to 10 years at an average rate of approximately 0.1 foot per year. The stage trend curve indicates somewhat of an erratic pattern of decline and rise over the past 5 years. This may be the result of data collection error.

2.4 At Omaha, the water surface elevation at a Sioux City discharge of 30,000 cfs has shown no significant change over the past 10 years. The average rate of decline over this time period has been approximately 0.01 foot per year.

2.5 A summary of the change and rate of change at each gage is provided in Table 1-S5.

2.6 The Mean Monthly Discharge plots for Sioux City, Iowa (Figures 10-S5) are updated to include data through 1990. A dashed reference line at the 30,000 cfs discharge represents the normal full service navigation flow at Sioux City. Overall flows have continued a steady decline each year since 1986.

3. WATER SURFACE SLOPE ANALYSIS.

3.1 Figures 11-S5 and 12-S5 show the water surface profile slope trends for the study reach divided into 20-mile increments. Analysis of the data collected since the mid-1970s indicates that while minor trends are evident in each reach,

they seldom last for more than four years and are usually offset by the succeeding trend. Except for the reach 745 to 725, insignificant changes in the slope profile have occurred over the past five years. Reach 745-725 exhibited a 5 percent increase in slope between 1989 and 1990. No significant change was noted along that reach between 1979 and 1989. This sudden change might be due to a data collection error or anomaly and will need to be monitored in future updates.

3.2 Figure 13-S5 presents the slope profiles for 1957, 1979, and 1990. The slope profile is relatively unchanged from 1979 to 1990, but in some cases shows a marked change from that of 1957. The plot indicates that some control mechanism exists between Gavins Point Dam and river mile 750, and that this control is causing an abrupt change in the slope profile between river miles 785 and 765.

4. CHANNEL CROSS-SECTIONAL ANALYSIS.

4.1 Composite cross sections representing each of the four study reaches were developed for years in which hydrographic survey information is available. Plots for the river reach from 731.82 to 727.00 are provided on Figure 14-S5. Due to budget constraints in 1990, no surveys were conducted in the study reaches and therefore no information is available for 1990. The four study reaches for the 1989 analysis, designated in 1960 river mileage, are 734 to 727, 720 to 715, 674 to 669, and 617 to 612. The composite cross sections were developed by combining channel cross sections obtained at intervals of 500 or 1000 feet throughout a study reach into a single average channel cross section. The process of compositing involves extracting construction reference plane elevations and channel depth data from hydrographic survey maps for each cross section, and converting this information to elevations, above mean sea level, at intervals of 25 feet across the channel. This data was processed using a computer program and analyzed to determine the following channel cross-sectional characteristics:

a. A composite cross section representative of each reach for each year;

b. The average bed elevation and depth below a reference elevation in each reach for the entire cross section and for the 300-foot navigation channel area, which extends 300 feet from the concave bank;

c. The mean cross-sectional area for the entire cross section and the navigational channel area below the reach reference elevation;

d. Average channel width; and

e. The percentage of the total cross-sectional area contained within the navigation channel segment.

Reference elevations used for the study reaches are shown in Table 2-S5. These data were used to develop the graphic plots listed in the following discussion.

4.2 Channel and cross-sectional data for the four study river reaches were updated as shown on Figures 15-S5, 16-S5, 17-S5, and Table 3-S5. An analysis of the cross sections in Figure 14-S5 shows general degradation and channel narrowing until 1978. From 1978 to 1981, the channel exhibited aggradation. Since 1981 the cross section has remained relatively stable. A comparison of the 1981 and 1989 composites shows very little overall change in the channel cross-section over this time period. Figure 17-S5 and Table 3-S5 support the aforementioned observations.

4.3 The original report made the assumption that by 1981, the river's modified regime was no longer having an impact on the river's characteristics, with the exception of bed degradation. The modified regime refers to the change in channel cross section shape, from wide and shallow to deep and narrow, and to the accretion of sediment between dike structures. This assumption is supported by Figures 14-S5, 15-S5, and 16-S5. Significant total channel area decreases in reach 674-669 from 1983 to 1984 were compensated for by increases from 1984 to 1986. The trend continued with the total channel area increasing significantly from 1986 to 1989. Reach 617 - 612 has remained relatively stable over the past ten years. The trend of total area increase observed since 1984 in reach 720 - 715 continued through 1989. The aggradation that occurred in reach 734 - 727 in 1985 and 1986 was more than compensated for in 1988 and 1989 and a significant increase in total channel area is noted in this reach also. A closer examination of the individual and composite cross sections indicates that very little change occurred in the reach downstream of the Floyd River confluence. In the reach between the Big Sioux River and Floyd River, the navigation channel remained relatively stable, while the non-navigation portion of the channel experienced narrowing and aggradation. A lack of data prevents an explanation of this phenomena. Figure 17-S5 indicates the percentage of the total channel area occupied by the navigation channel along the study reaches remained relatively stable through 1988. A moderate decrease in this percentage was noted in all 4 reaches in 1989. Decreases in the navigation channel percentage may be due to the sustained drought management of the mainstem system which regulates the flows at Sioux City.

III. GROUNDWATER AND OXBOW LAKE STUDY

Data have been collected on groundwater levels, oxbow lake levels, and Missouri River stages at and near Winnebago and Tieville Oxbow Lakes through 1984. At Winnebago Lake, groundwa-

ter data were collected since 1966, and at Tieville Oxbow Lake, data were collected since 1979. Oxbow lake levels have been measured at both sites since 1979. River stage data generally have been taken concurrently with groundwater data. Figures 18-S5 and 19-S5 are maps showing the locations of the observation wells at each lake. Figures 20-S5 through 22-S5 and Table 4-S5 are included with this report, unchanged from the 1985 update. Since 1984, only one additional year of groundwater data was recorded for this study. Due to the lack of significant additional data since 1984, this update does not present any discussion or conclusions for this study.

IV. TRIBUTARY IMPACTS ANALYSIS

As a supplement to the 1987 update, a study was prepared which identified the extent to which the Missouri River tributaries are degrading, associated problems, and the influence of the Missouri River degradation upon the tributaries. An analysis of the historical cross-sectional data of the tributaries was made to determine the degradation trends for each tributary. Cross-sectional data were collected from twelve tributaries in the study area. The twelve streams are listed in Table 5-S5. The cross sections were analyzed to compute the average depth, top width, change in top width, and the change in average depth. Differences in thalweg and average depth were compared with the changes in water surface elevation in the Missouri River for the same time period (see Table 6-S5). The tributaries of the Missouri River are degrading and are causing infrastructure problems for both public agencies and private individuals. Tributary degradation may be linked to any of the three following causes: activity by man (channelization, channel straightening, and levee construction); increased runoff caused by adjacent land use; and/or degradation of the Missouri River. Although tributary degradation is occurring below river mile 645, the Missouri River cannot be the cause since the reach downstream of this point is aggrading. Missouri River degradation upstream of river mile 645 may be a factor in tributary degradation. An analysis of the historical trends indicated that three-fourths of the tributaries experienced degradation trends that paralleled degradation on the Missouri River. Although no general hypothesis about the Missouri River's influence on tributary degradation can be concluded based upon the historical trends presented, there is a strong indication of a relationship. While the study shows that some of the tributaries may be influenced by the Missouri River, there are other factors affecting tributary degradation.

V. BED SEDIMENT ANALYSIS

1. OVERVIEW. The high flow in 1984 is not representative

of the typical annual discharges which continue to shape the channel. The 1984 flow produced greater-than-normal degradation, and deposited a lot of large-particle sediment. So, while data exist for the bed composition in October 1984, the high flow event preceding that set of data is not included in this analysis of bed sediment. Comparisons of bed material was made for data sets from September or October of 1972, 1973, 1979 and, where available, 1988. Since sediment size data for the river's non-channel (point bar) area were available only for 1972 and 1973, those graphs are not presented here. Although that information showed an increase in material size between the two sets of data, a one-year period is not a reliable indicator of long-term trends. Therefore, this analysis considered data from the channel area (outside of the bends) as well as for the composite (total) channel. Size of bed material varies considerably along this 150-mile reach. Consequently, the general trends of the data plots were analyzed in order to see the overall effect of the river through this reach, rather than analyzing plots' yearly extremes.

2. D35 GRAIN SIZE. This analysis indicates trends in the D35 (35% greater than) grain size, or the coarser sediment in the sampled areas.

2.1 Analysis of samples gathered from the channel area indicated a general increase in particle size from 1972 to 1979 (Fig. 23-S5). The largest increase was between miles 695 and 670, where particle size increased by nearly 30 percent.

2.2 The composite channel between the years 1972 and 1979 (Fig. 24-S5) showed trends similar to the navigation channel, with an average particle size increase of about 30 percent between miles 695 and 675. The composite channel during that seven-year period outside the 695-675 reach averaged a 15 percent increase.

2.3 The composite channel between the years 1972 and 1988 showed a typical particle size increase in its upstream area of about 15 percent. Toward the mid-reach area, the increase was closer to 30 percent. And downstream of Blair, the average increase is nearly 50 percent.

3. D50 GRAIN SIZE. This analysis is based on the median particle size of the streambed material.

3.1 Figure 25-S5 shows that the size of the average bed particle in the channel area has increased at rates of up to 50 percent between 1972 and 1979 from around mile 710 to 680. Further downstream, from mile 660, the increase generally is less than 15 percent.

3.2 The composite channel (Fig. 26-S5) shows a change in bed material similar to the navigation channel. From 1972 to 1979, the increase in bed grain size of up to 50 percent between

miles 695 and 670 tapers off to less than 15 percent downstream of mile 625. The greatest change during the 1970s took place just downstream of Decatur.

3.3 The 1988 data for the composite channel show a steadier increase in particle size, starting at about 20 percent in the upstream area. The average increase in the mid-reach area (around mile 675) is about 30 percent, and toward the end of the reach the particle size increase is about 35 percent. For the entire study period of 1972 to 1988, the greatest change occurred toward the downstream end of the study reach, just north of Omaha.

4. D90 GRAIN SIZE. The D90 set of sediment samples comprises the finer ten percent of the bed material.

4.1 For 1972 and 1979, bed material in the channel area became coarser by about 30 percent in the area from mile 695 to mile 670 (Fig. 27-S5). Downstream of this area, the typical size increase in average particle size was about 20 percent.

4.2 The composite channel data up to 1979 (Fig. 28-S5) indicated an average increase of about 30 percent between miles 695 and 675. Upstream of that reach, the increase was about 25 percent. Downstream of mile 675, the increase in particle size dropped below 25 percent.

4.3 For the composite channel between 1972 and 1988, the average particle size in the upstream area increased by about 20 percent. The average size increase in the mid-reach area was about 30 percent. In the downstream area of the study reach, the average particle size increased by about 35 percent.

5. SUMMARY. The three sets of samples (D35, D50, D90) discussed above yielded similar results in terms of where the river bed was becoming coarser and by how much. Between 1972 and 1988, the data groups showed that the bed material in the composite channel had become coarser by 35 to 50 percent in the downstream area of the study reach. The rate of change was about 30 percent for all three groups in the mid-reach area. And the average particle size in the upstream area had increased by only 20 percent. The increase in the average particle size of the streambed material appears to show that the study reach is becoming more stable, especially at its downstream end.

VI. ANALYSIS OF DEGRADATION

1. GENERAL. Future degradation trends were analyzed, with degradation projections to the year 2000. Short-range projections of additional declines in water surface elevations for Yankton, Sioux City, Decatur, and Omaha were developed by

analyzing historical trends in water surface profiles, channel cross-sectional characteristics, and stage-discharge relationships. The projections reflect the anticipated decline in water surface elevation through the year 2000 for a discharge of 30,000 cfs at the Sioux City gage.

1.1 Due to the short period of record and the scatter shown in the data, two curves representing a range of predicted degradation were developed in lieu of a single curve.

1.2 The 1989 and 1990 data points have been added to the Yankton curve, Figure 29-S5. Both points fall slightly below the lower projection line developed in the original update. The channel is armored from Gavins Point Dam to Yankton so increased degradation is not expected through this stretch. One possible cause for the increased rate of water surface elevation decline could be attributed to channel widening. However, current data do not allow for conclusive explanations. A third curve, approximately one foot below the original lower projection curve was generated to better represent the degradation trends at Yankton.

1.3 The plot of the data for Sioux City, Figure 30-S5, shows the 1989 and 1990 data falling between the two projected curves. Update reports prepared prior to 1987 had predicted that the upper curve was a better representation of the ultimate degradation. Although 1985 through 1987 data indicated that slightly more degradation was occurring than was projected by this upper curve, the data for 1988 through 1990 indicate that this earlier prediction is accurate.

1.4 Figure 31-S5, a plot of the Decatur data, shows the 1989 and 1990 data falling just below the upper projection curve. Since 1977, the plotted data have fallen very closely to or above the minimum degradation curve, indicating that the degradation rate is decreasing at the gage location.

1.5 The 1989 and 1990 data for Omaha, plotted on Figure 32-S5, fall on or slightly below the upper projection line. Since 1985, the data points have plotted on or just below this line. This indicates that the original projections were reasonable, and that the upper curve may be a closer prediction of the anticipated decline in water surface elevation.

2. CORE DRILL DATA. No core drill data has been obtained since 1980, so Figure 33-S5, which is a plot of elevation versus river mile at which 1/4 inch, 3/4 inch, and 1 1/2 inch grain sizes and hardpans locations were encountered, is included with this report, unchanged, from the previous update.

VII. CONCLUSION

1. Analysis of recent historical trends, which are presented as adjusted water surface profiles, water surface decline/rise plots, stage-discharge trend plots, and channel cross-section plots, indicate an overall decrease in the degradation rate for the navigation project from Sioux City, Iowa to the Platte River.

2. Only one set of data (1987) has been collected for the groundwater and oxbow lake study since 1984. Future analysis of Missouri River oxbow lake levels are contingent on available data.

3. Many of the Missouri River tributaries are experiencing degradation which is causing infrastructure problems. Causes of the degradation most likely stem from channel altering by man, increased runoff, and Missouri River degradation. Nearly three-fourths of the tributaries studied had degradation trends paralleling degradation on the Missouri River. While not conclusive, this suggests that there may be a relationship between the Missouri River degradation and degradation on the tributaries.

4. The 1983 update reported a coarsening trend in the bed material between 1978 and 1980 samples. Analysis of bed sediment in 1972, 1979 and 1988 confirms that the river bed material is coarsening, indicating that the river bed is becoming more stable.

5. This update indicates that recent stage and channel geometry data generally follow the projected degradation rates previously identified in the original degradation report. At Yankton, the data fall slightly below the lower projection line developed in the original degradation report. A third curve was generated for Yankton which better represents the lower limit of degradation. At the Decatur and Omaha stations, the data are falling near or above the upper projection line, indicating a possible decrease in the degradation rate. At Sioux City the degradation rate, since 1982, has fallen in line with the projected rates.

6. The high discharges in 1984 caused an increase in degradation that was largely offset in 1985 and 1986 and stabilized in 1987 through 1990. There was a decreasing trend in the degradation rate, suggesting a possible decrease in the overall trend. Future updates, barring further unusual hydrologic events, should be more conclusive in determining whether or not the actual degradation rate is below the projected rate.

APPENDIX A

TABLES

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<u>TABLE</u>	<u>TITLE</u>
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TABLE 1-S5

W.S. ELEVATION, CHANGE AND RATE OF CHANGE AT Q = 30,000 CFS

<u>Year</u>	<u>W.S. Elevation</u> (feet above msl)	<u>Elevation Change</u> (feet)	<u>Rate</u> (ft/yr)
YANKTON			
1931	1165.0		
1980	1157.6	-7.4	-0.15
1982	1156.9	-0.7	-0.35
1983	1156.7	-0.2	-0.20
1984	1156.6	-0.1	-0.10
1985	1156.1	-0.5	-0.50
1986	1156.2	+0.1	+0.10
1987	1156.0	-0.2	-0.20
1988	1155.8	-0.2	-0.20
1989	1155.7	-0.1	-0.10
1990	1155.3	-0.4	-0.40
SIOUX CITY			
1929	1083.5		
1980	1075.3	-8.2	-0.16
1982	1075.0	-0.3	-0.15
1983	1075.3	+0.3	+0.30
1984	1074.7	-0.6	-0.60
1985	1074.5	-0.2	-0.20
1986	1074.2	-0.3	-0.30
1987	1073.8	-0.4	-0.40
1988	1074.2	+0.4	+0.40
1989	1074.6	+0.4	+0.40
1990	1074.7	+0.1	+0.10
DECATUR			
1957	1039.1		
1980	1033.9	-5.2	-0.16
1982	1033.7	-0.2	-0.10
1983	1033.6	-0.1	-0.10
1984	1033.4	-0.2	-0.20
1985	1033.2	-0.2	-0.20
1986	1033.5	+0.3	+0.30
1987	1033.0	-0.5	-0.50
1988	1033.2	+0.2	+0.20
1989	1032.8	-0.4	-0.40
1990	1032.9	+0.1	-0.10
OMAHA			
1936	968.8		
1980	964.9	-5.2	-0.09
1982	964.8	-0.1	-0.05
1983	964.8	0.0	0.00
1984	964.4	-0.4	-0.40
1985	964.7	+0.3	+0.30
1986	964.9	+0.2	+0.20
1987	964.8	-0.1	-0.10
1988	964.8	0.0	0.00
1989	964.4	-0.4	-0.40
1990	964.4	0.0	0.00

Prepared By Bjx
Reviewed By _____

TABLE 2-S5

CROSS-SECTIONAL ANALYSIS STUDY REACH REFERENCE ELEVATIONS

<u>Reach Location</u> (1960 River Mileage)	<u>Reference Elevation</u> (feet above msl)
734 TO 727	1081.0
720 to 715	1068.0
674 to 669	1018.0
617 to 612	963.0

Prepared By JL
Reviewed By JL

TABLE 3-S5

CHANGES IN CHANNEL DEPTHS BELOW REFERENCE ELEVATION

<u>REACH</u> (1960 river mile)	<u>CHANNEL AREA CONSIDERED</u>	<u>1952</u>	<u>1975</u>	<u>1979</u>	<u>1981</u>	<u>1984</u>	<u>1986</u>	<u>1988</u>	<u>1989</u>	<u>1952-1975</u>	<u>1975-1979</u>
		(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	DIFFERENCE (ft)	DIFFERENCE (ft)
734-727	Total Section	11.6	17.1	20.7	19.5	21.6	19.0	21.2	19.8	-5.5	-3.6
	Navigation Channel	16.7	23.0	24.2	22.1	24.5	22.4	23.6	22.1	-6.3	-1.2
	Thalweg	19.5	25.4	28.9	27.5	28.2	27.0	29.5	27.6	-5.9	-3.5
720-715	Total Section	10.4	16.9	19.7	18.6	19.1	18.9	20.5	19.9	-6.5	-2.8
	Navigation Channel	14.7	22.5	23.5	21.7	21.4	21.6	23.5	23.2	-7.8	-1.0
	Thalweg	22.3	28.8	28.2	26.5	25.6	25.5	27.7	27.6	-6.5	+0.6
674-669	Total Section	7.7	13.1	15.3	15.7	12.6	14.6	17.3	15.6	-5.4	-2.2
	Navigation Channel	14.8	18.0	18.6	18.6	14.3	17.6	19.3	18.7	-3.2	-0.6
	Thalweg	18.8	22.5	24.7	23.2	19.0	21.7	23.6	22.7	-3.7	-2.2
617-612	Total Section	9.2	11.2	13.2	11.8	12.1	10.8	13.0	11.4	-2.0	-2.0
	Navigation Channel	13.8	15.9	15.7	14.2	15.6	14.2	14.0	15.1	-2.1	+0.2
	Thalweg	19.0	21.4	22.3	19.7	20.0	18.9	19.3	19.1	-2.4	-0.9

<u>REACH</u> (1960 river mile)	<u>CHANNEL AREA CONSIDERED</u>	<u>1979-1981</u>	<u>1981-1989</u>	<u>1975-1989</u>	<u>1988-1989</u>
		DIFFERENCE (ft)	DIFFERENCE (ft)	DIFFERENCE (ft)	DIFFERENCE (ft)
734-727	Total Section	+1.2	-0.3	-2.7	+1.4
	Navigation Channel	+2.1	0.0	+0.9	+1.5
	Thalweg	+1.4	-0.1	-2.2	+1.9
720-715	Total Section	+1.1	-1.3	-3.0	+0.6
	Navigation Channel	+1.8	-1.5	-0.7	+0.3
	Thalweg	+1.7	-1.1	+1.2	+0.1
674-669	Total Section	-0.4	+0.1	-2.5	+1.7
	Navigation Channel	0.0	-0.1	-0.7	+0.6
	Thalweg	+1.5	+0.5	-0.2	+0.9
617-612	Total Section	+1.4	+0.4	-0.2	+1.6
	Navigation Channel	+1.5	-0.9	+0.8	-1.1
	Thalweg	+2.6	+0.6	+2.3	+0.2

Prepared By BGX
Reviewed By _____

TABLE 4-S5

Winnebago Oxbow Lake
GROUNDWATER TABLE ELEVATIONS, WATER SURFACE ELEVATIONS, AND PRECIPITATION
FOR JUNE OF EACH YEAR
(Base Level - 1,000 m.s.l.)

Well Location	1967	1970	1971	1972	1973	1974	1975	1976	1978	1979	1980	1981	1982	1983	1984
Ground Water Elevations															
(feet)															
S-3	61.3	59.5	60.4	60.3	60.3	58.5	60.2	58.1	60.0	59.0	57.3	55.7	55.4	61.0	61.9
W-1	58.8	57.0	58.2	58.0	57.8	56.2	58.3	56.0	57.0	56.6	55.0	53.5	53.2	58.7	57.7
W-2	60.9	57.8	59.0	59.0	59.6	57.7	58.5	56.8	57.0	57.3	56.1	54.2	54.0	59.9	60.0
W-3	58.0	56.7	57.6	57.0	56.0	55.2	57.0	54.0	MSG.	55.4	53.4	52.0	51.9	56.0	57.4
W-4	59.7	57.5	58.2	57.5	59.5	57.2	58.0	56.0	56.0	56.8	55.7	53.5	53.3	59.8	59.6
W-5	—	59.4	60.0	59.5	57.7	57.0	60.2	56.2	59.5	58.3	55.9	MSG.	MSG.	MSG.	MSG.
W-6	—	59.3	60.1	60.0	59.0	57.7	61.4	57.2	58.8	58.3	55.9	MSG.	MSG.	59.7	MSG.
W-7	—	58.4	59.1	59.0	58.0	57.2	60.1	55.9	58.1	57.6	MSG.	MSG.	MSG.	MSG.	MSG.
W-8	—	59.5	60.0	59.8	58.3	57.6	60.3	56.7	58.8	58.1	56.2	MSG.	MSG.	MSG.	MSG.
Oxbow Lake Elevations															
(feet)															
Winnebago Oxbow Lake	—	—	—	—	—	—	—	—	—	54.7	51.9	51.5	52.2	52.4	56.0
River Stages															
(feet)															
River Mile	708.6	56.6	57.0	56.7	52.2	52.2	53.9	56.0	54.2	54.7	55.2	52.2	52.6	52.2	56.2
	711.0	58.7	59.4	59.8	59.4	54.8	56.4	58.7	56.6	57.2	57.5	54.7	54.3	54.5	58.5
Precipitation															
Location															
Sioux City	27.02	27.25	29.56	22.04	31.93	25.79	23.13	20.66	29.99	26.40	26.11	17.21	25.29	34.78	33.28
Onawa	38.31	22.44	27.15	26.71	36.94	35.38	29.39	21.14	30.55	25.58	28.12	20.79	28.93	45.82	39.37

- Notes: 1. Groundwater levels, river stages and oxbow lake levels represent measurements taken in June of each year.
2. Precipitation values represent annual totals measured from July through June.

Prepared By Box
Reviewed By TL

TABLE 4-S5

TABLE 5-S5

TRIBUTARIES SELECTED FOR STUDY



<u>TRIBUTARY</u>	<u>STATE</u>	1960 MISSOURI RIVER MILEAGE OF <u>TRIBUTARY CONFLUENCE</u>
Beaver Creek	Nebraska	806.3
Bow Creek	Nebraska	787.6
Lime Creek	Nebraska	776.2
Vermillion River	South Dakota	771.9
Aowa Creek	Nebraska	745.3
Elk Creek	Nebraska	737.5
Big Sioux River	Iowa	734.0
Wood Creek	Nebraska	691.5
Elm Creek	Nebraska	691.0
Soldier River	Iowa	664.0
Boyer River	Iowa	635.2
Pigeon Creek	Iowa	619.9

Prepared By
Reviewed By

TABLE 6-S5

DEGRADATION RATES FOR THE
MISSOURI RIVER AND ITS TRIBUTARIES

TRIBUTARY	AVERAGE DEPTH RATE OF CHANGE (FT/YEAR)	THALWEG RATE OF CHANGE (FT/YEAR)	PERIOD (YRS)	W.S. ELEVATION RATE OF CHANGE (FT/YEAR)	PERIOD (YRS)
Beaver	-0.14	-0.22	1955-56	-0.20	1957-86
Bow	-0.07	-0.07	1959-86	-0.13	1957-86
Lime	+0.01	+0.01	1964-86	-0.22	1965-86
Vermillion					
Site One	-0.30	-0.28	1973-86	-0.18	1973-86
	-0.12	-0.20	1961-86	-0.14	1960-86
Site Two	-0.12	-0.25	1961-86	-0.14	1960-86
Site Three	-0.10	-0.37	1957-84	-0.20	1957-84
Site Four	-0.20	-0.22	1961-86	-0.14	1960-86
Aowa					
Site One	-0.12	-0.17	1946-71	-0.21	1957-73
Site Two	-0.23	-0.46	1956-86	-0.22	1957-86
Elk					
Site Two	+0.02	-0.07	1965-86	-0.32	1965-86
	-0.07	-0.17	1931-86	-0.15	1929-86
Site Three	+0.03	-0.08	1954-86	-0.26	1957-86
Site Four	+0.03	-0.17	1954-86	-0.25	1957-86
Big Sioux					
Site One	-0.09	-0.59	1957-84	-0.27	1957-84
Site Two	+0.37	+0.37	1975-86	-0.12	1973-86
Site Three	-0.10	-0.20	1955-84	-0.27	1957-84
Wood	+0.25	+0.21	1961-86	-0.27	1960-86
Elm	-0.03	-0.13	1971-86	-0.12	1973-86
Soldier					
Site One	-0.18	-0.31	1966-86	-0.10	1965-86
Site Two	-0.10	-0.07	1958-86	-0.13	1957-86
Boyer					
Site One	-0.07	-0.01	1956-86	0.00	1957-86
Site Two	+0.01	+0.07	1945-86	0.00	1957-86
Pigeon					
Site One	-0.02	-0.08	1929-86	+0.01	1957-86
Site Two	+0.13	0.00	1956-86	+0.01	1957-86

Prepared By 
Reviewed By 

APPENDIX B
FIGURES

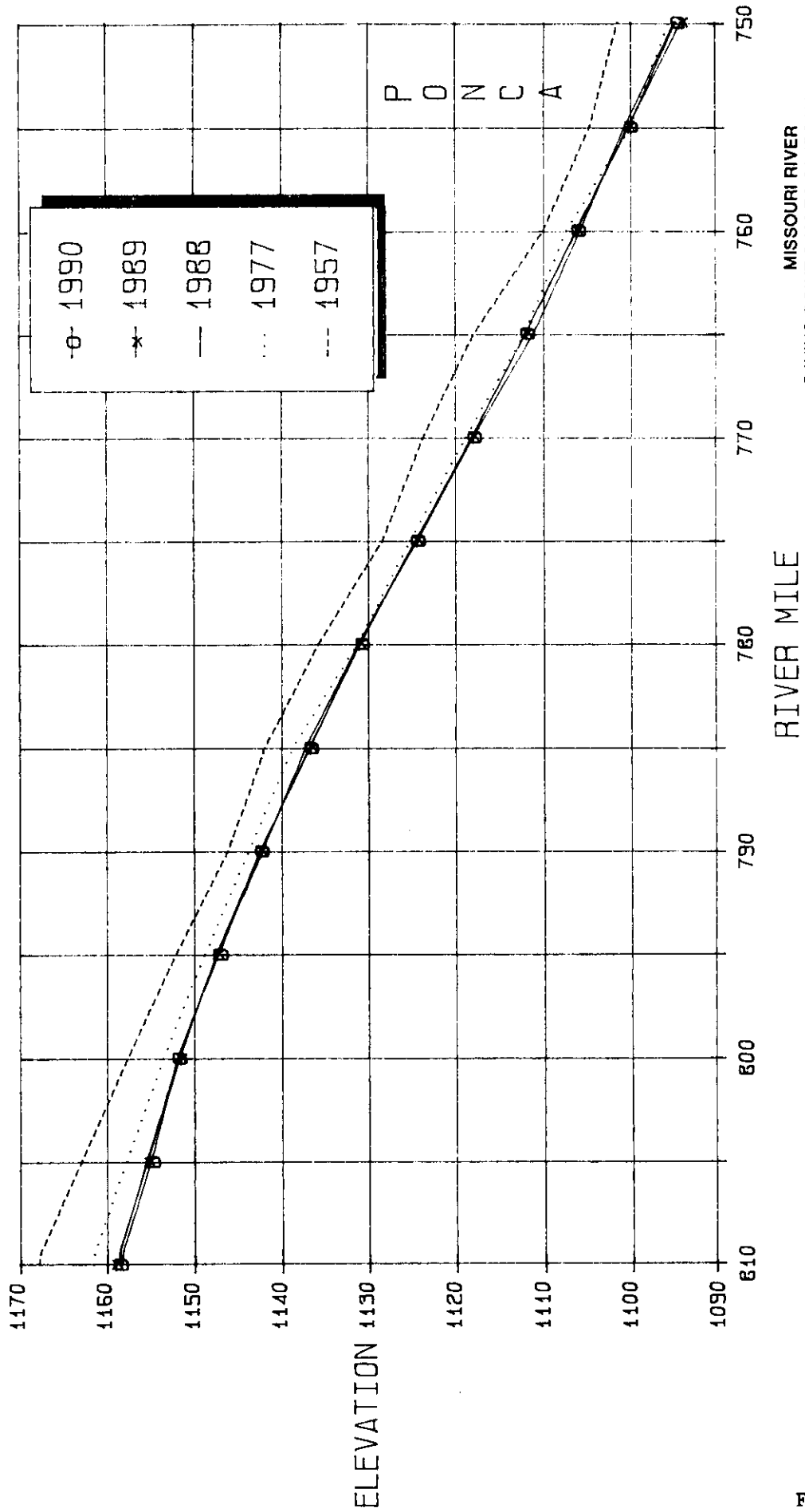
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ADJUSTED WATER SURFACE PROFILE 1957-1990



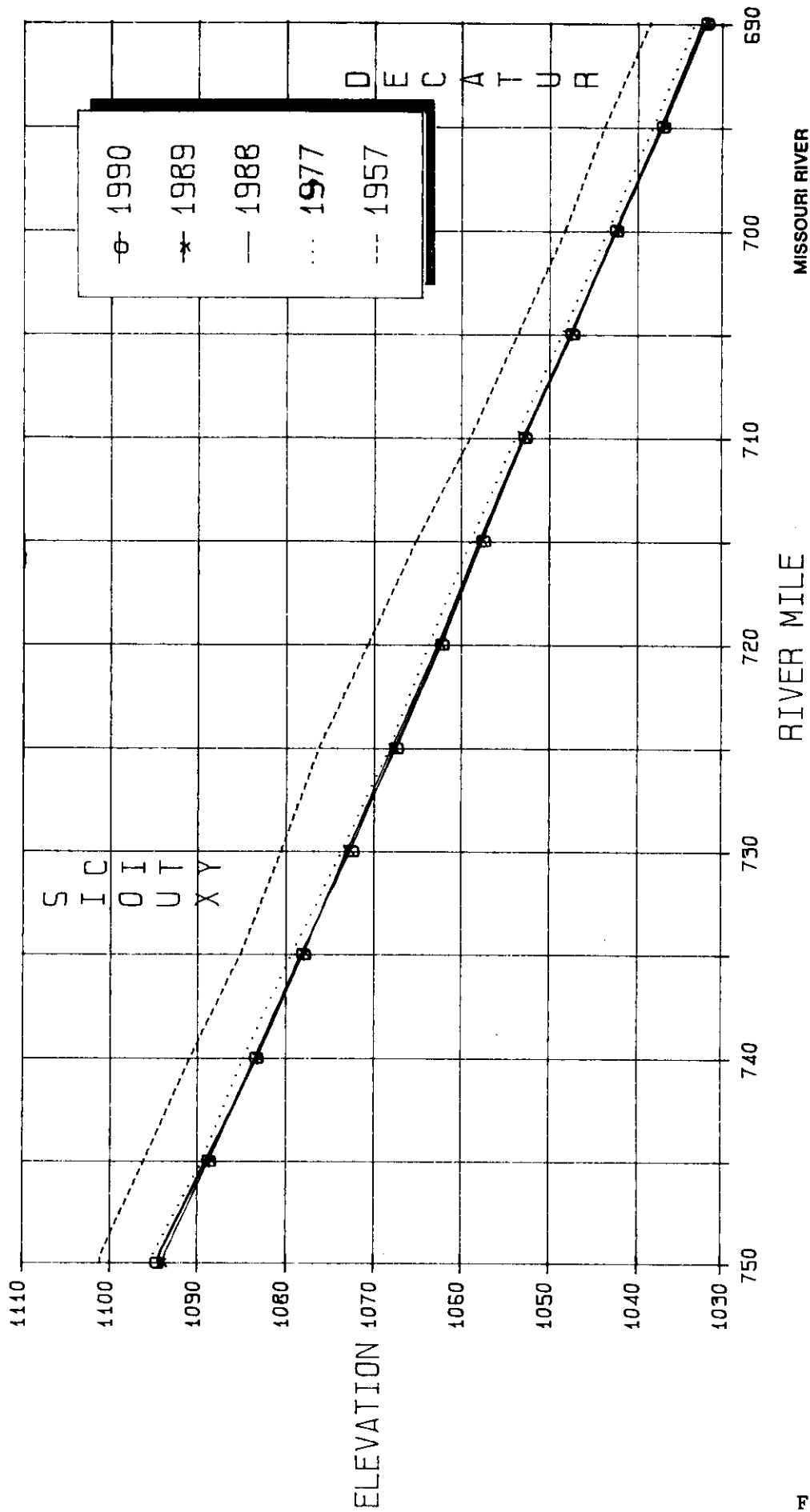
Prepared By 390
Reviewed By HL

MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
ADJUSTED WATER SURFACE PROFILE, 30000 CFS AT
SIOUX CITY, IA, RIVER MILE 810 TO 760

FIG. 1-S5

FIG. 1-S5

ADJUSTED WATER SURFACE PROFILE 1957-1990

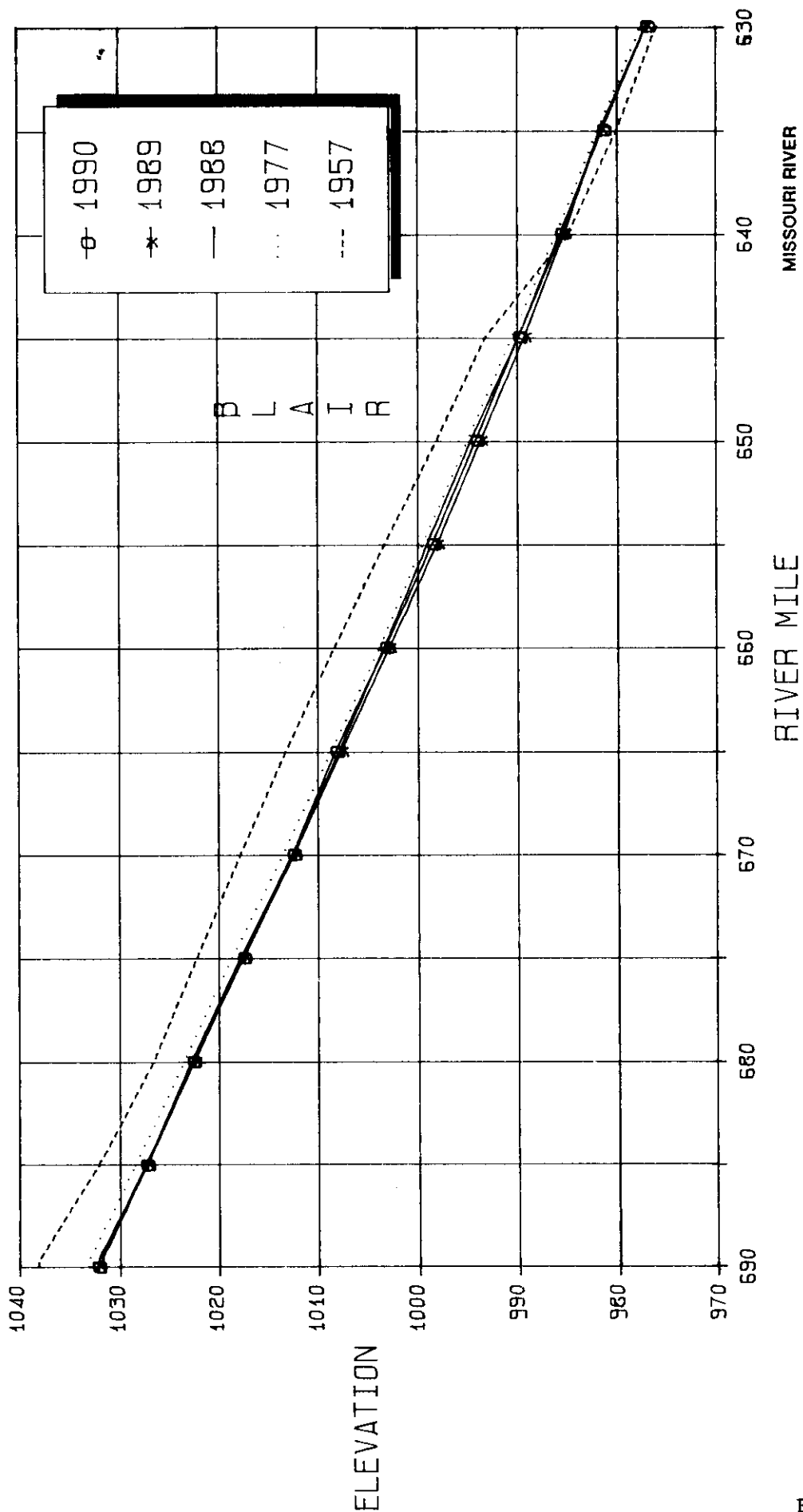


MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
ADJUSTED WATER SURFACE PROFILE, 30000 CFS AT
SIOUX CITY, IA, RIVER MILE 760 TO 890

Prepared By BZA
Reviewed By TZ

FIG. 2-S5

ADJUSTED WATER SURFACE PROFILE 1957-1990



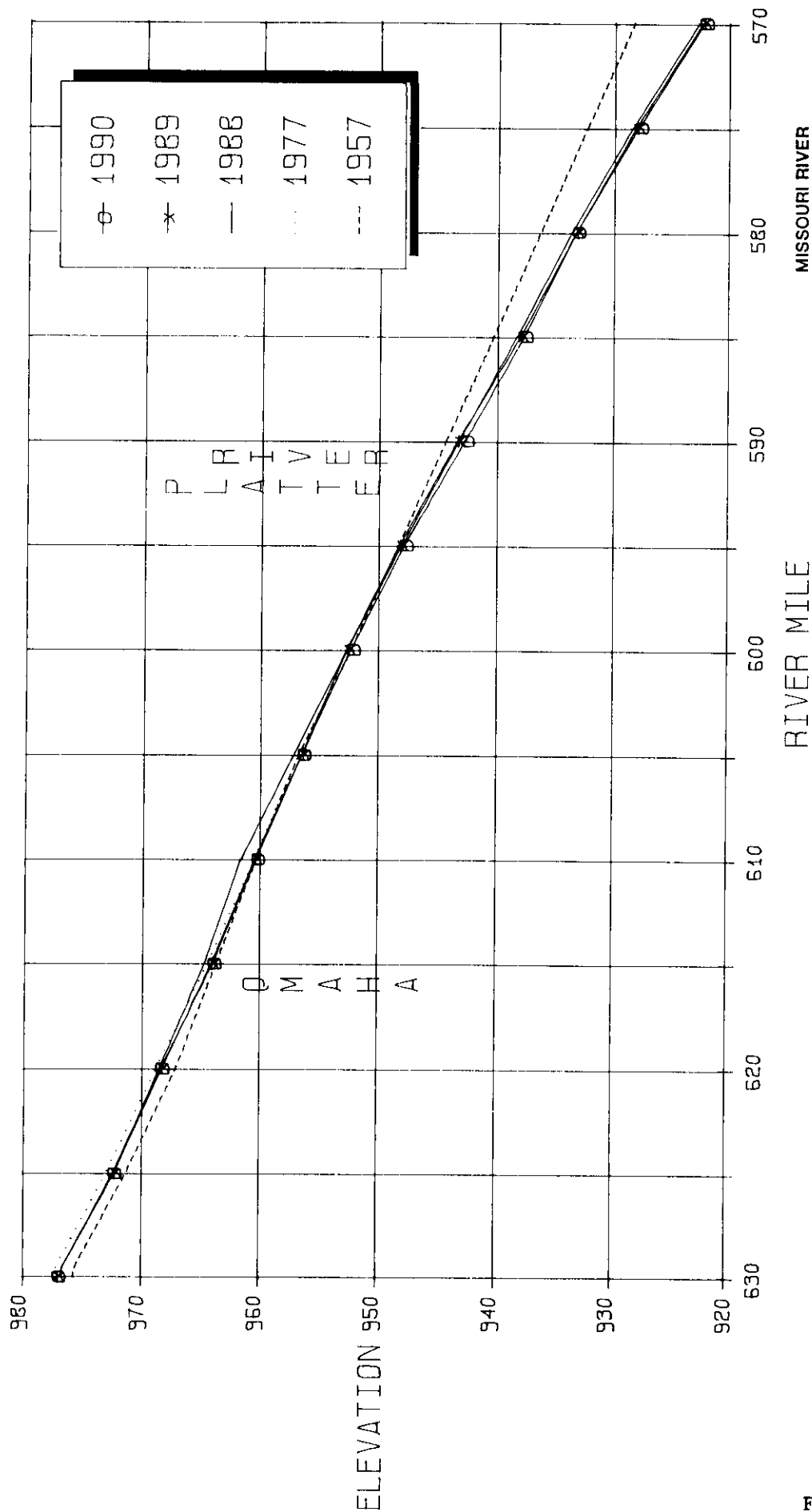
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
ADJUSTED WATER SURFACE PROFILE, 30000 CFS AT
SIOUX CITY, IA, RIVER MILE 690 TO 630

Prepared By *Bpd*
Reviewed By *[Signature]*

FIG. 3-S5

FIG. 3-35

ADJUSTED WATER SURFACE PROFILE 1957-1990



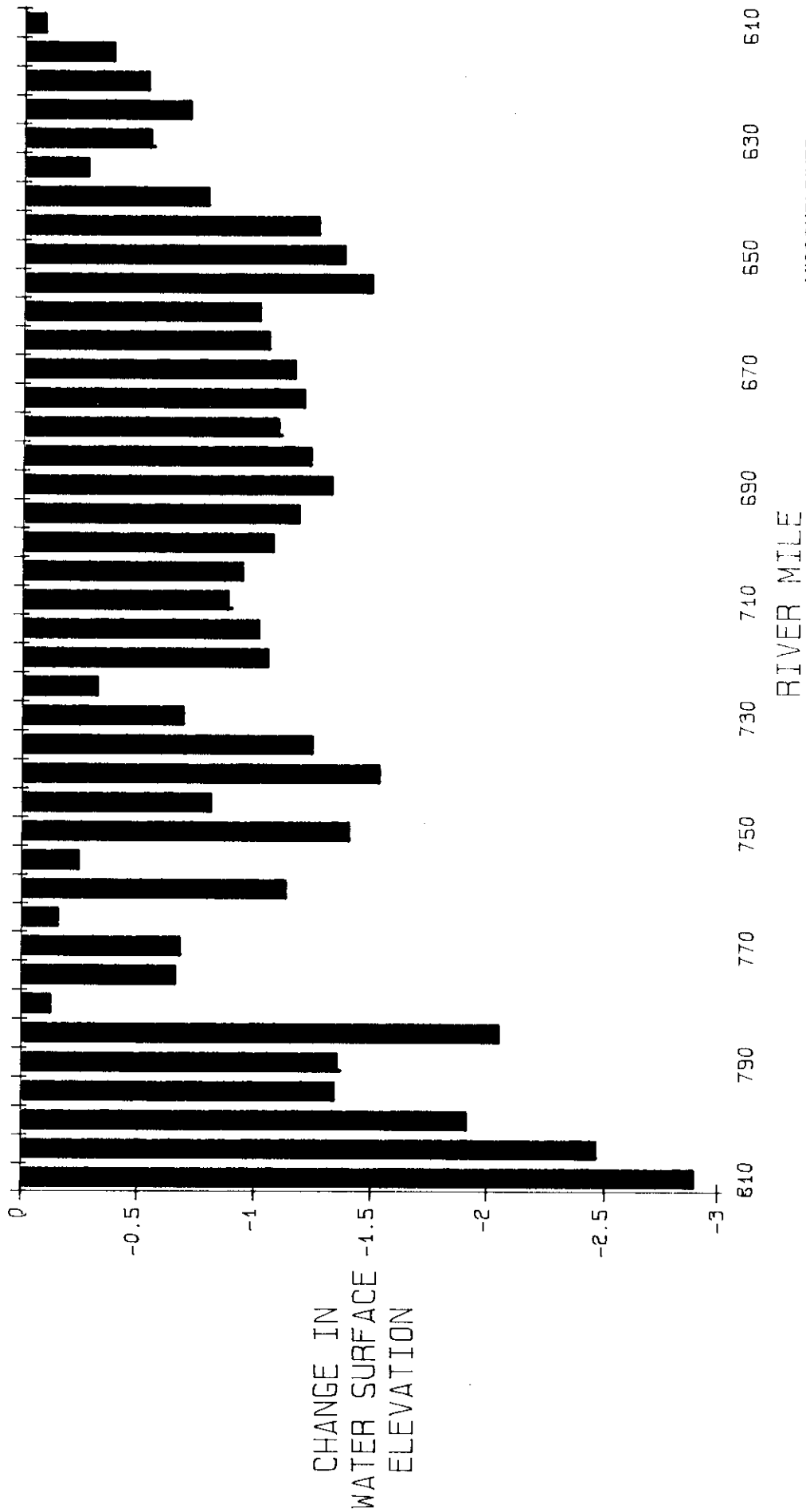
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
ADJUSTED WATER SURFACE PROFILE, 30000 CFS AT
SIOUX CITY, IA, RIVER MILE 630 TO 670

Prepared By 392
Reviewed By 24

FIG. 4-S5

FIG. 4-S5

WATER SURFACE DECLINE/RISE 1977 TO 1989



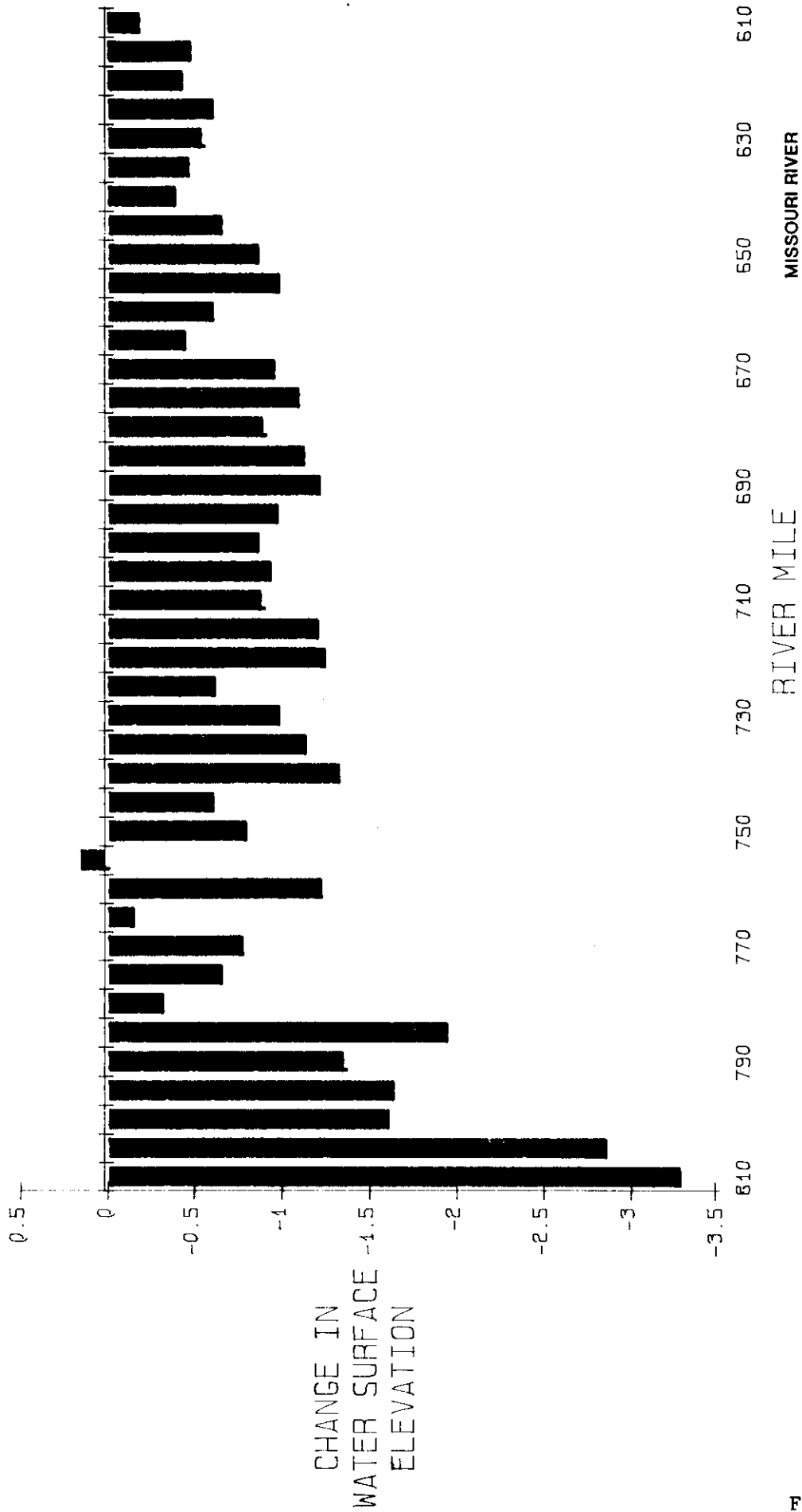
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
WATER SURFACE DECLINE/RISE - 1977 TO 1989

Prepared By 38d
Reviewed By ---

FIG. 5-S5

FIG. 5-S5

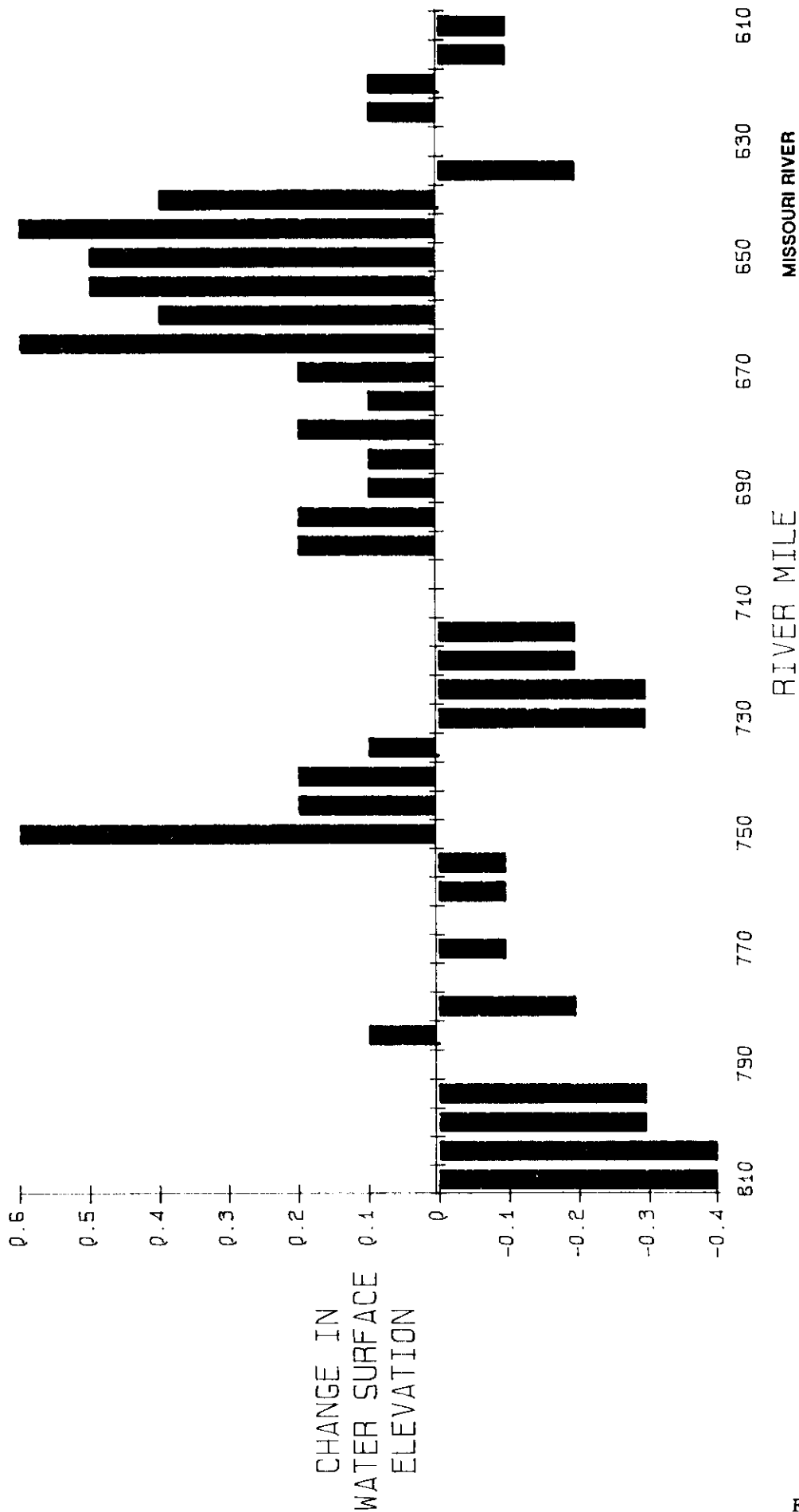
WATER SURFACE DECLINE/RISE 1977 TO 1990



MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
WATER SURFACE DECLINE/RISE - 1977 TO 1990

Prepared By 307
Reviewed By 1/2

WATER SURFACE DECLINE/RISE 1989 TO 1990



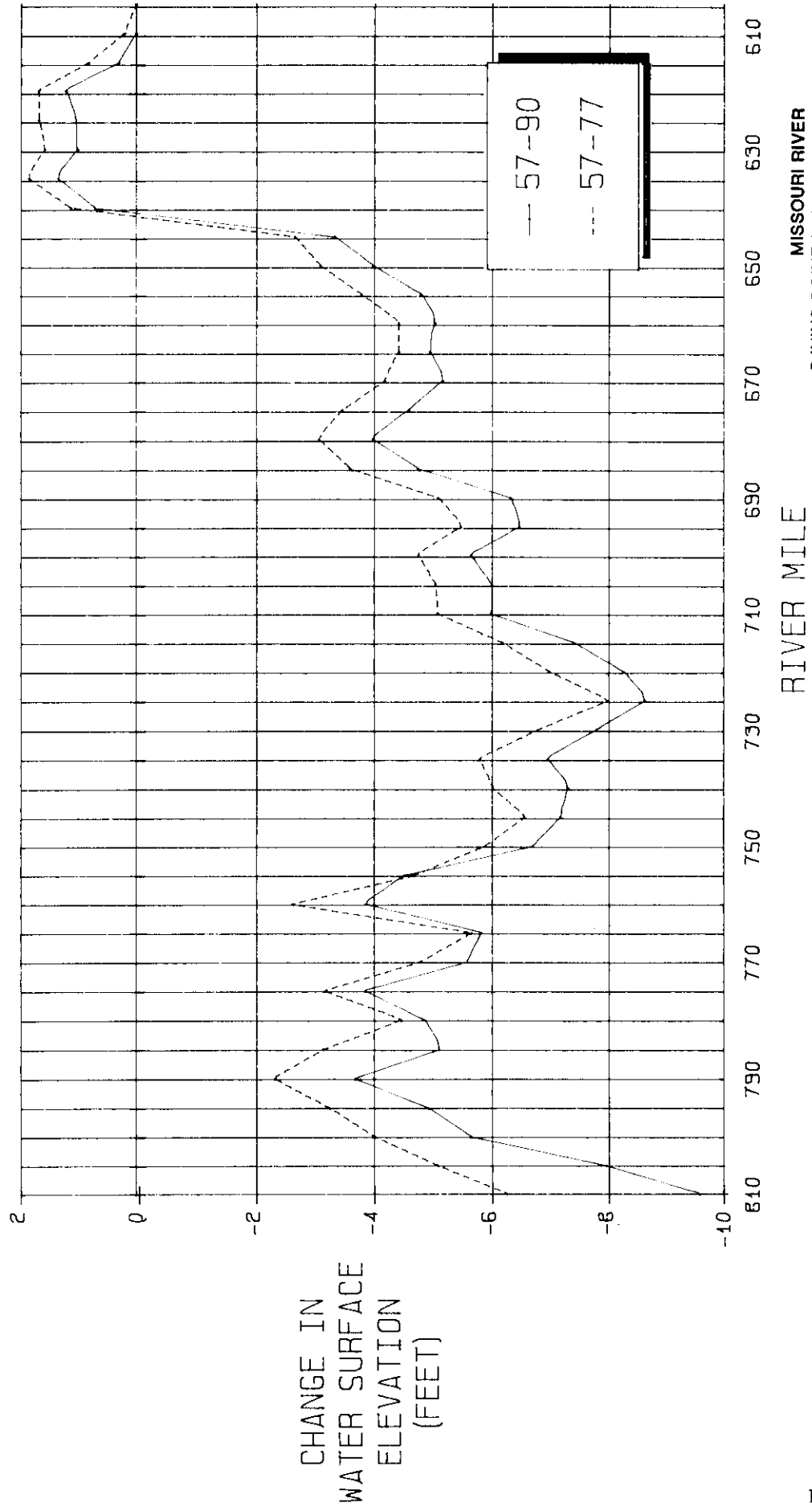
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
WATER SURFACE DECLINE/RISE - 1989 TO 1990

Prepared By 392
Reviewed By 215

FIG. 7-S5

FIG. 7-S5

WATER SURFACE DECLINE/RISE 1957 TO 1977 & 1957 TO 1990

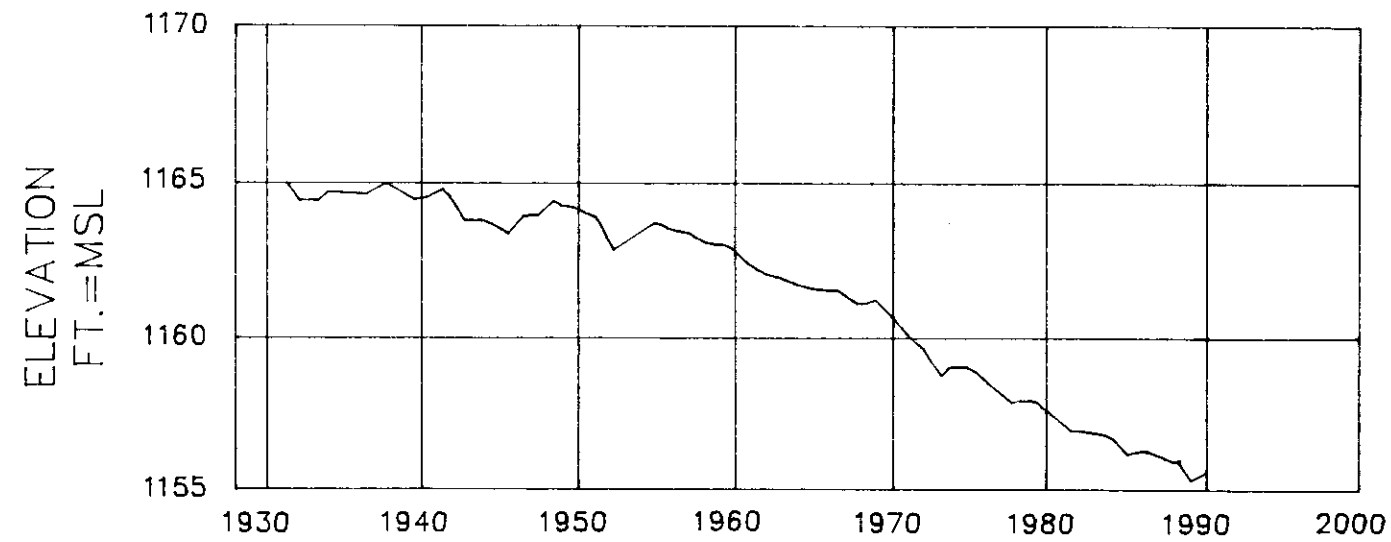


Prepared By 392
Reviewed By ---

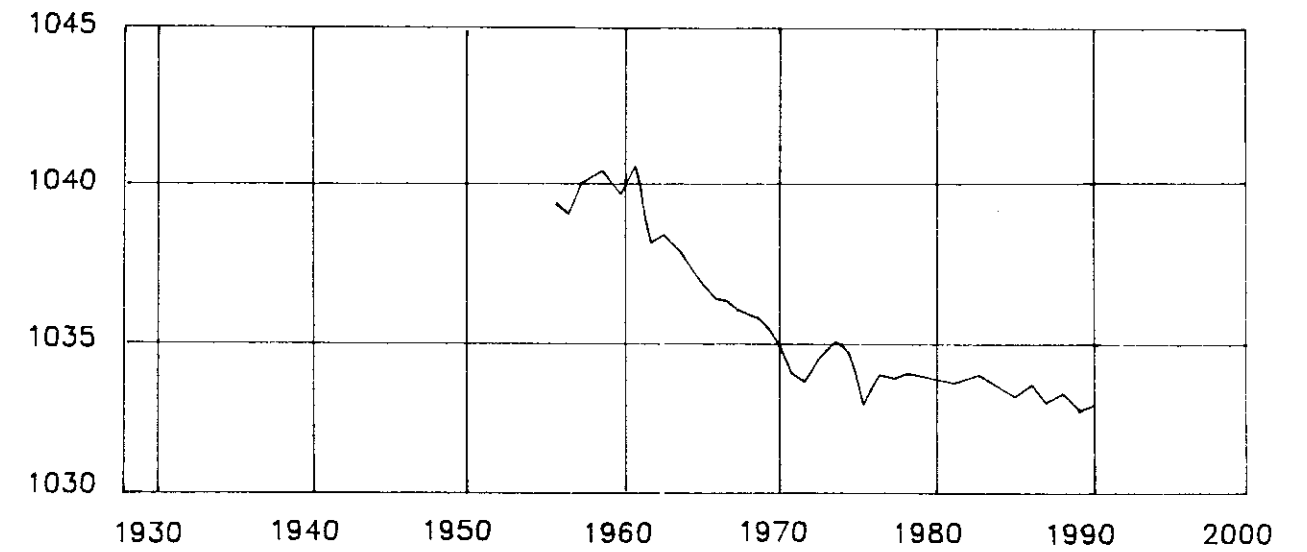
FIG. 8-S5

FIG. 8-S5

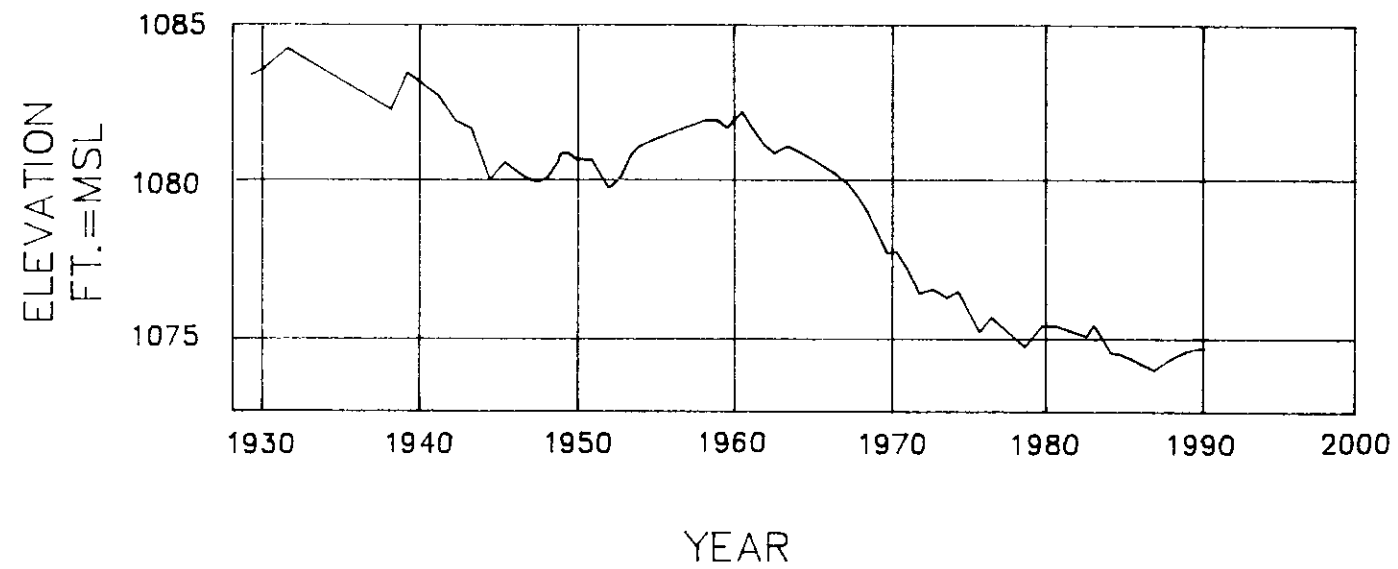
YANKTON



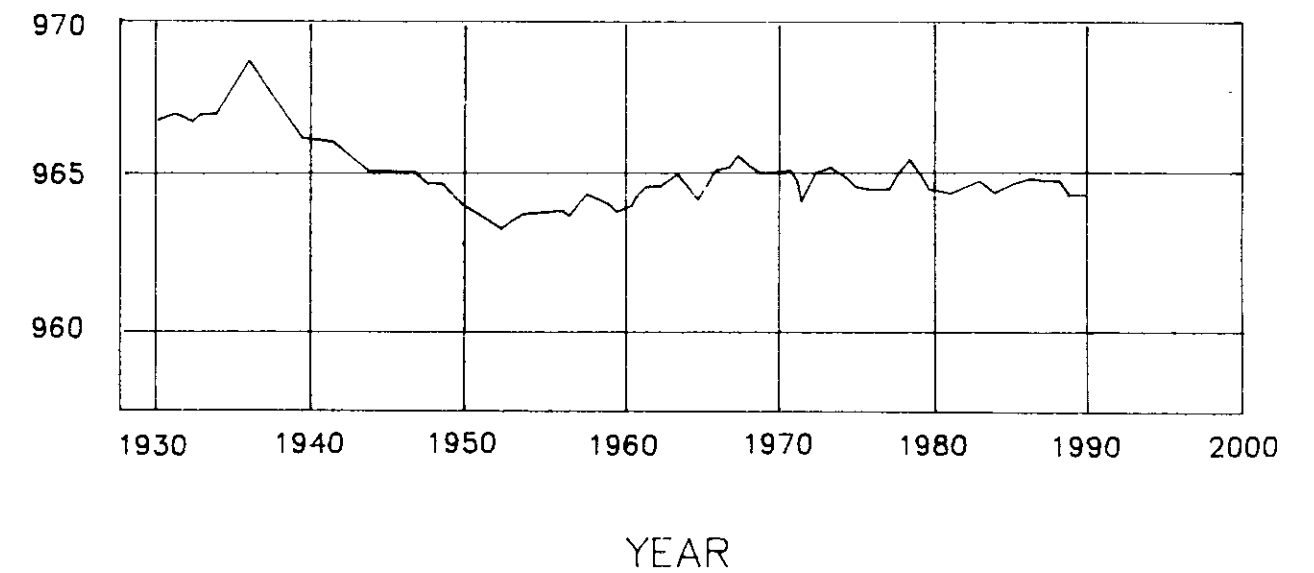
DECATUR



SIOUX CITY



OMAHA



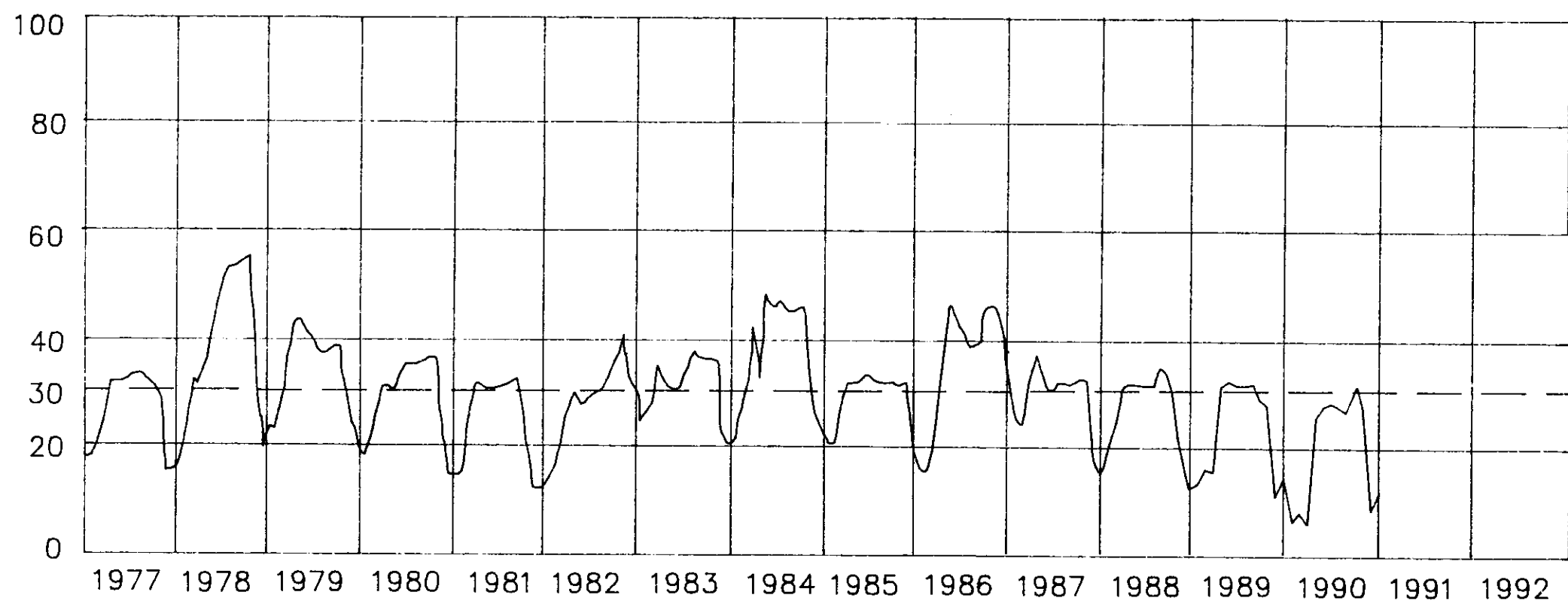
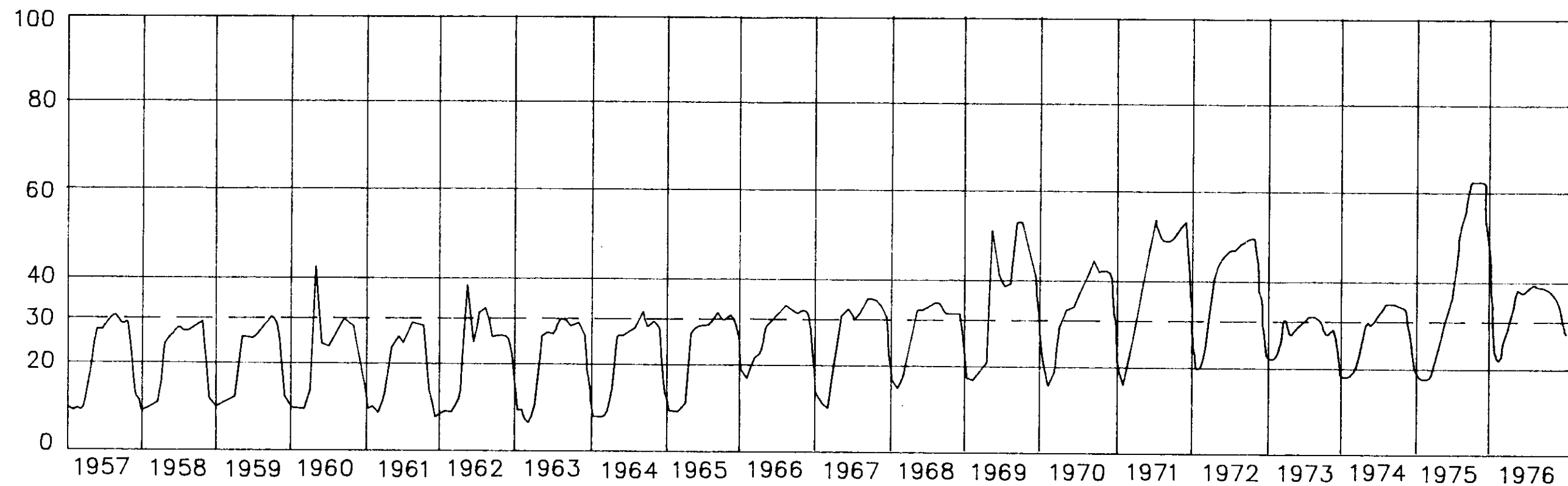
Prepared By Bjz
Reviewed By ---

MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY

STAGE TREND CURVES, 30000 CFS
YANKTON, SIOUX CITY, DECATUR, AND OMAHA

FIG. 9-S5

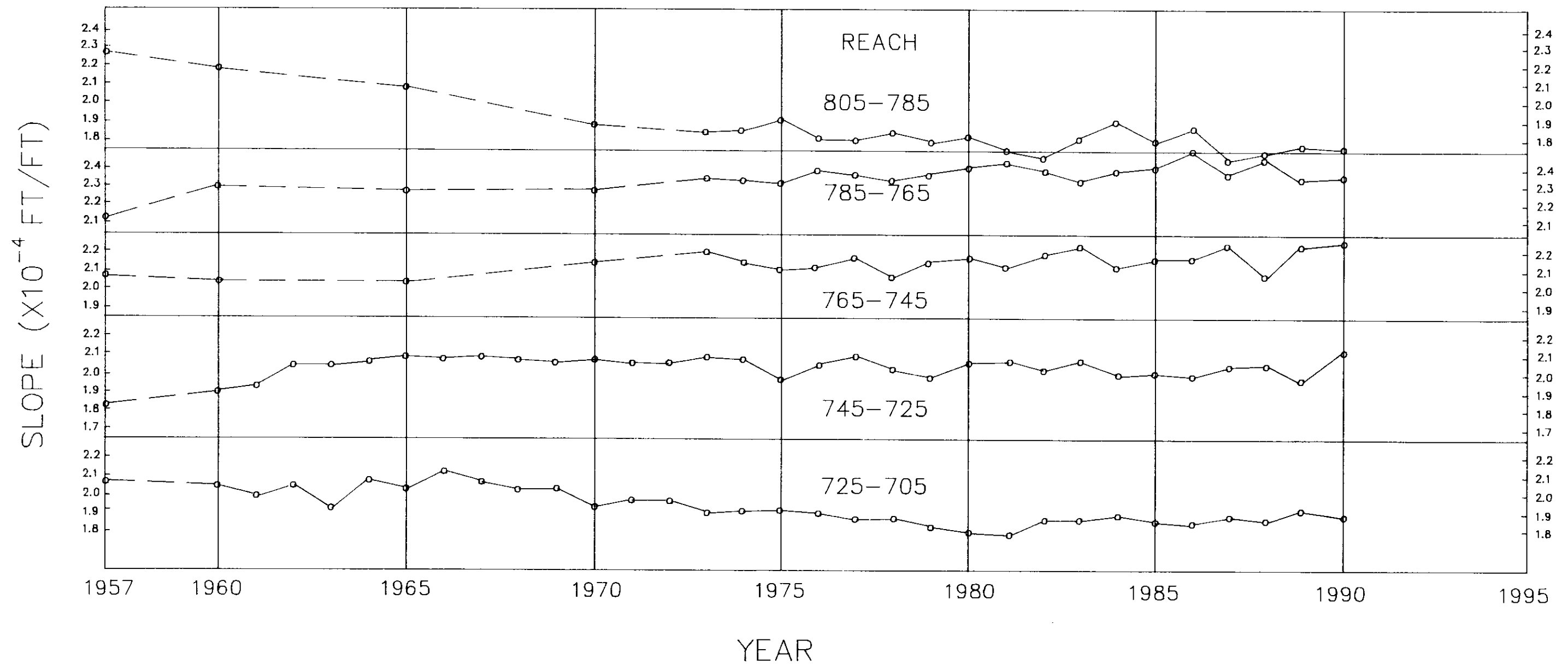
DISCHARGE IN THOUSAND C.F.S.



Prepared By Bga
Reviewed By _____

MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
MEAN MONTHLY DISCHARGE, SIOUX CITY, IA

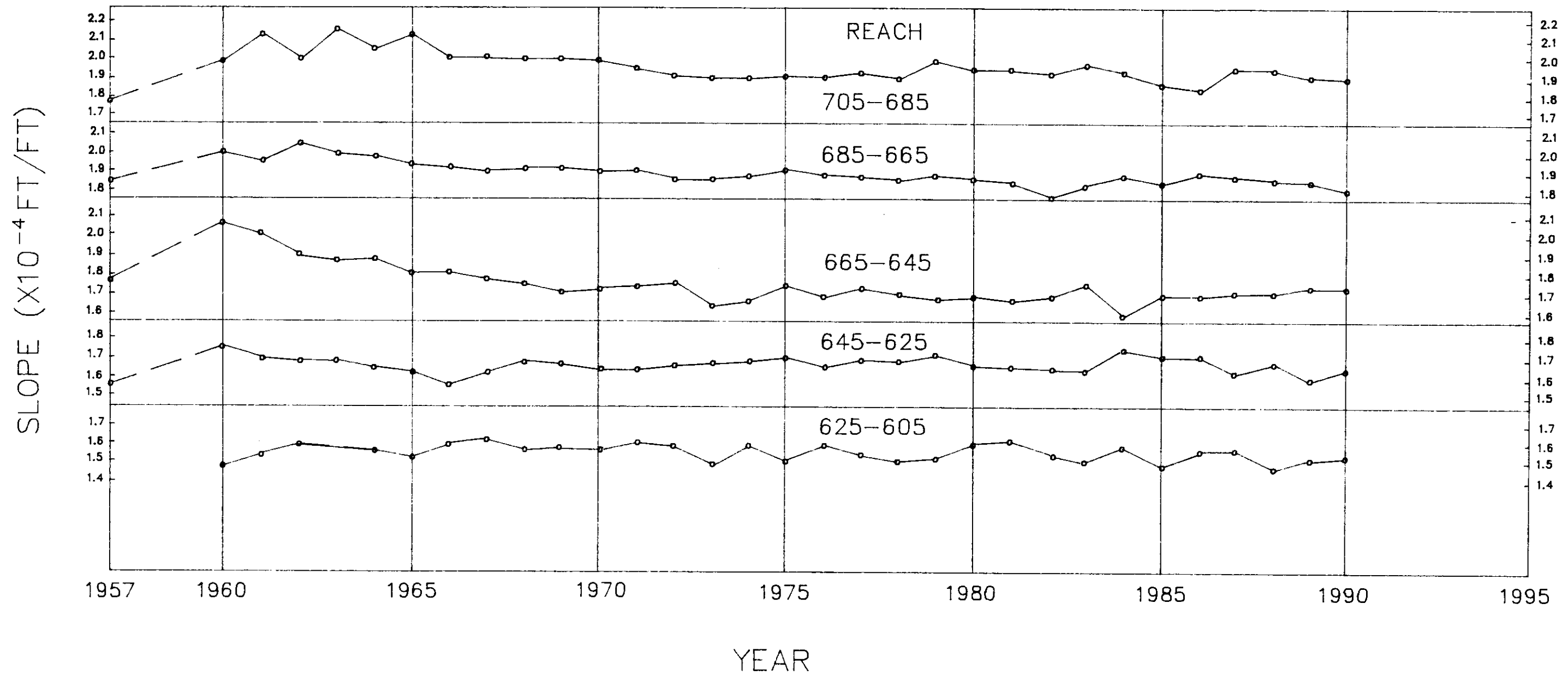
FIG. 10-S5



Prepared By BGA
 Reviewed By _____

MISSOURI RIVER
 GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
 SLOPE TRENDS - RIVER MILE 805 TO 705

FIG. 11-S5



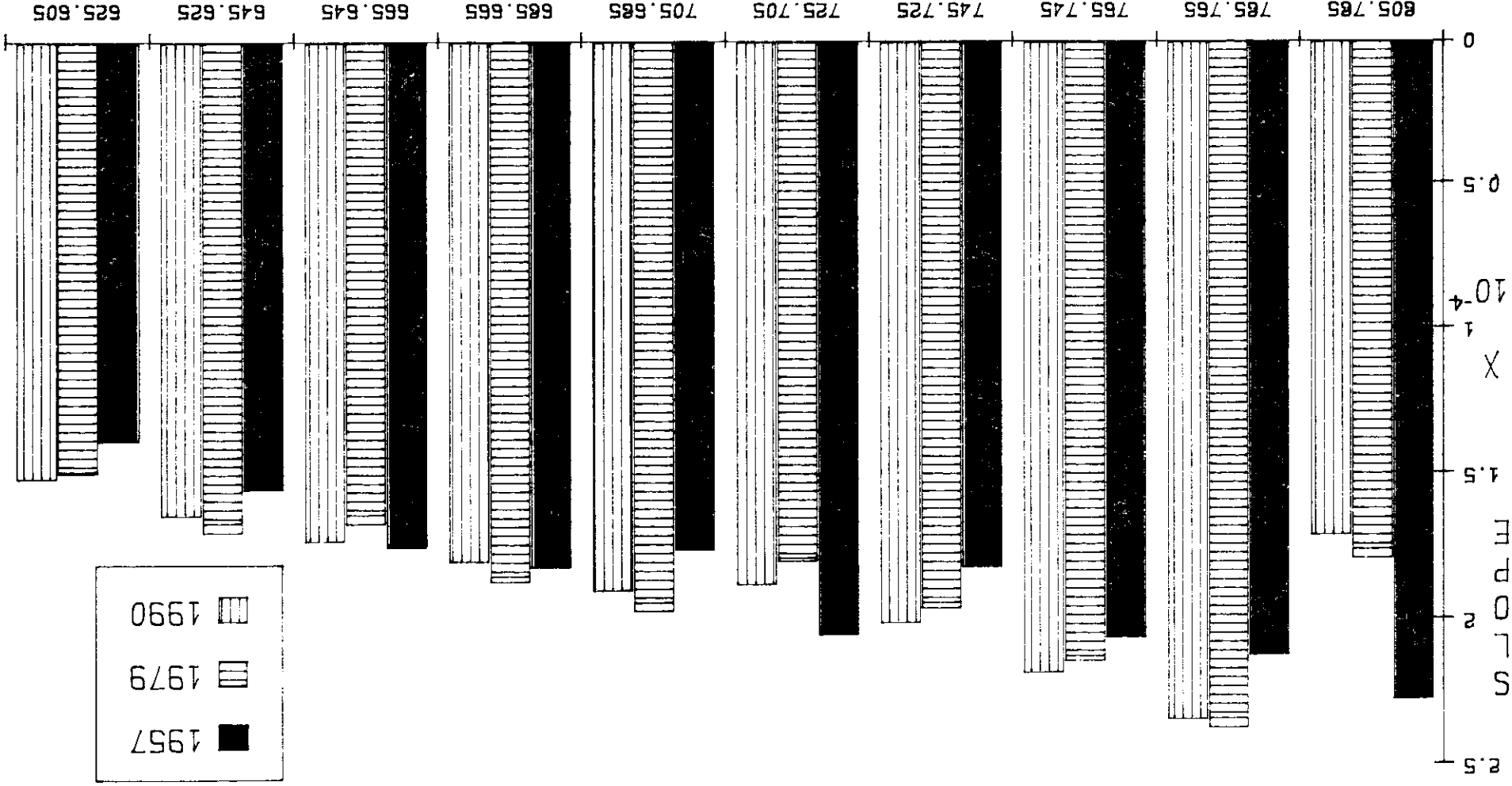
Prepared By 307
 Reviewed By _____

MISSOURI RIVER
 GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
 SLOPE TRENDS - RIVER MILE 705 TO 605

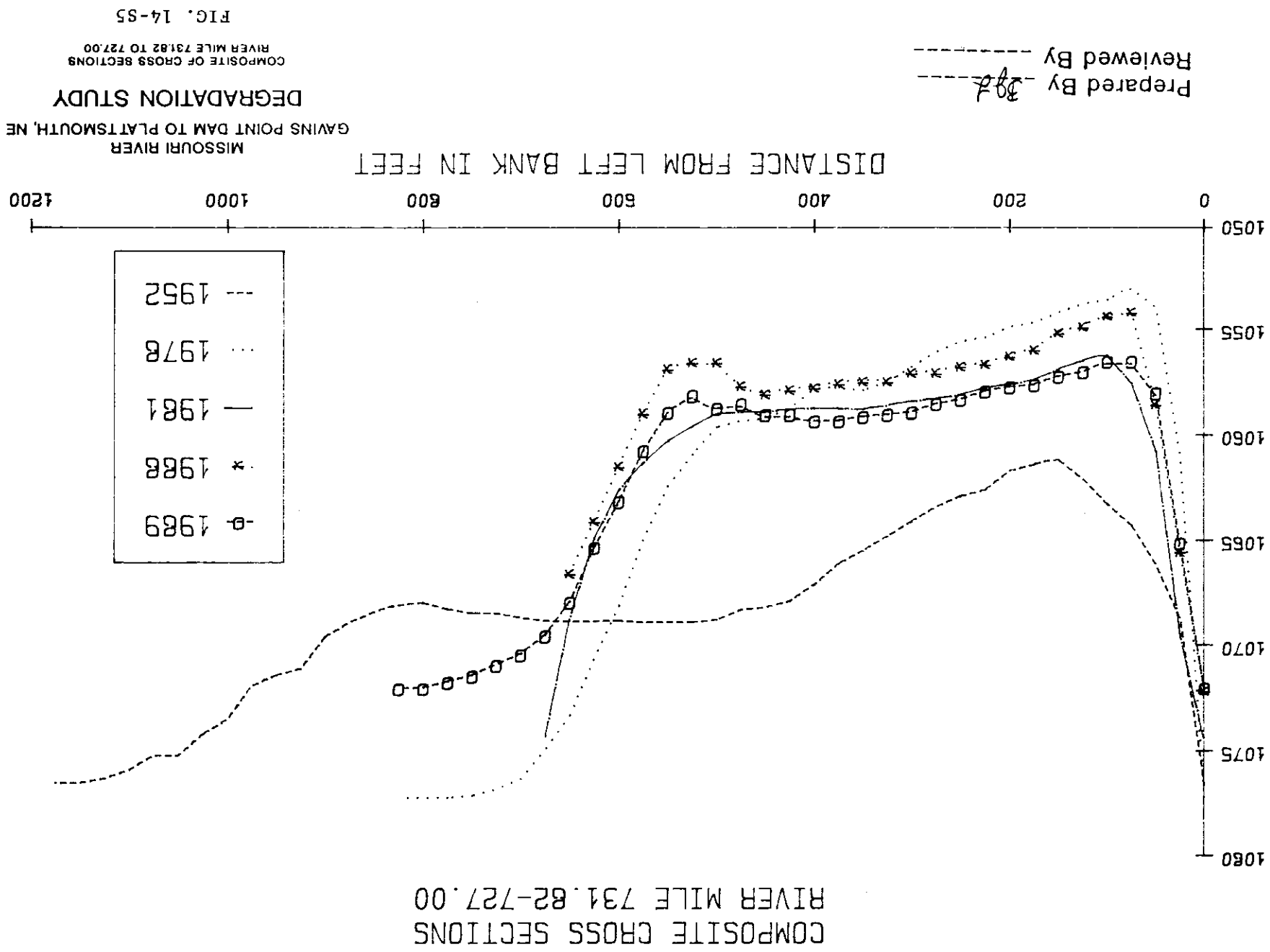
FIG. 12-S5

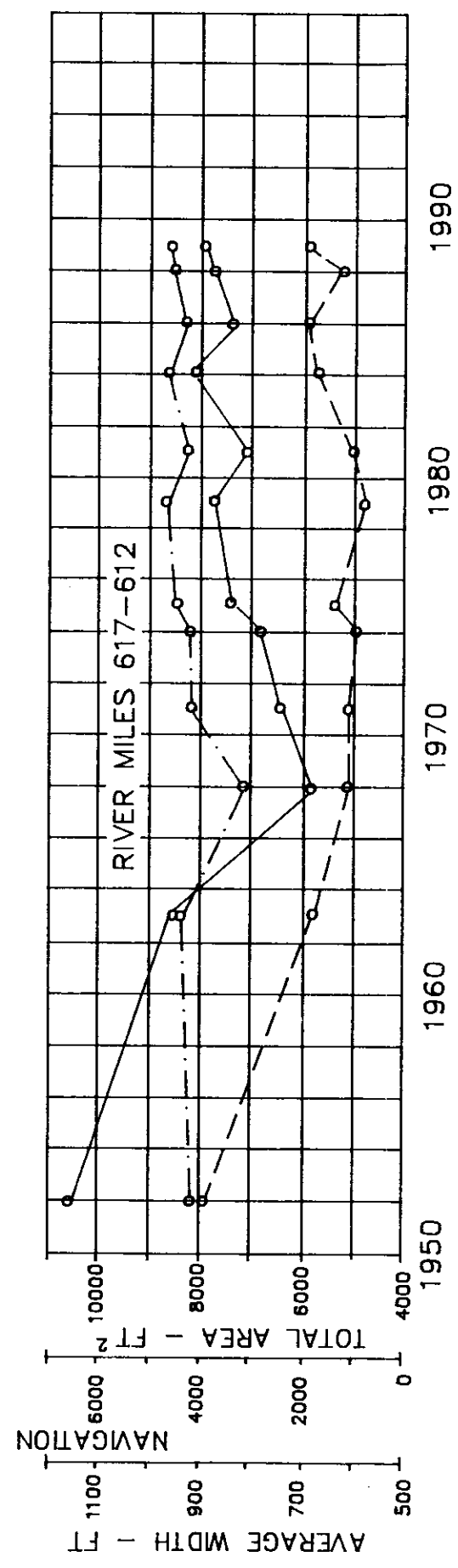
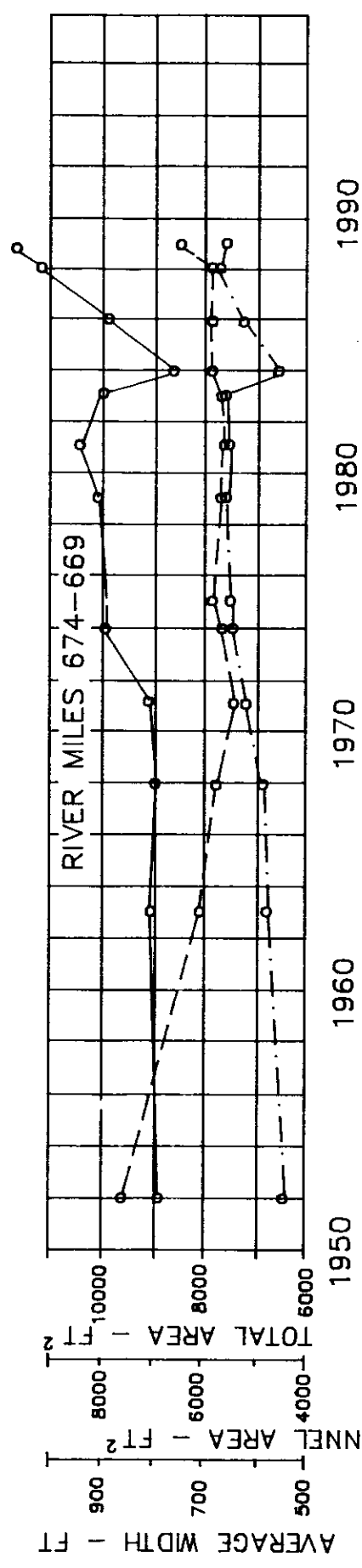
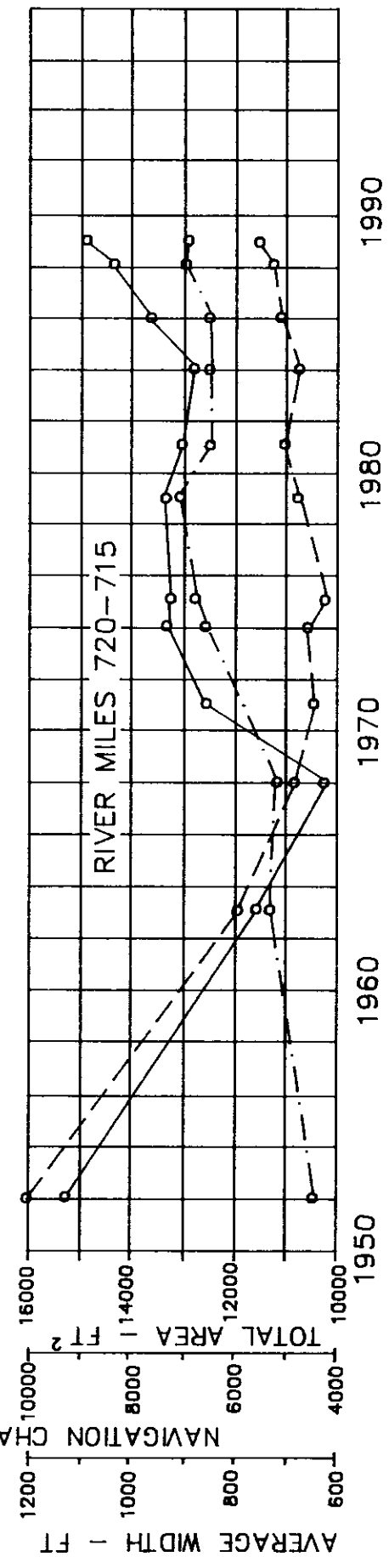
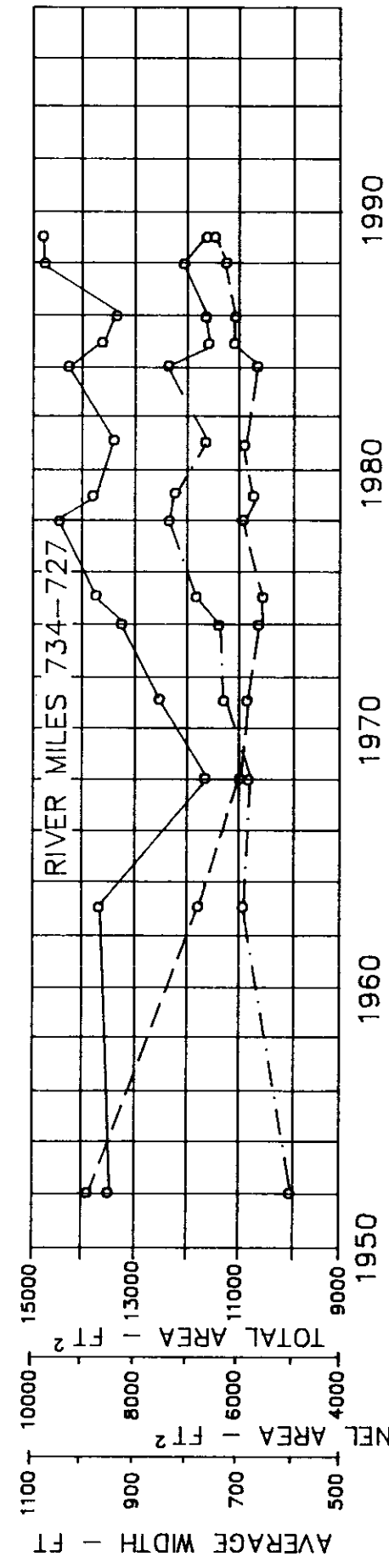
Prepared By *Boz*
Reviewed By _____

SLOPE PROFILES 1957, 1979, 1990



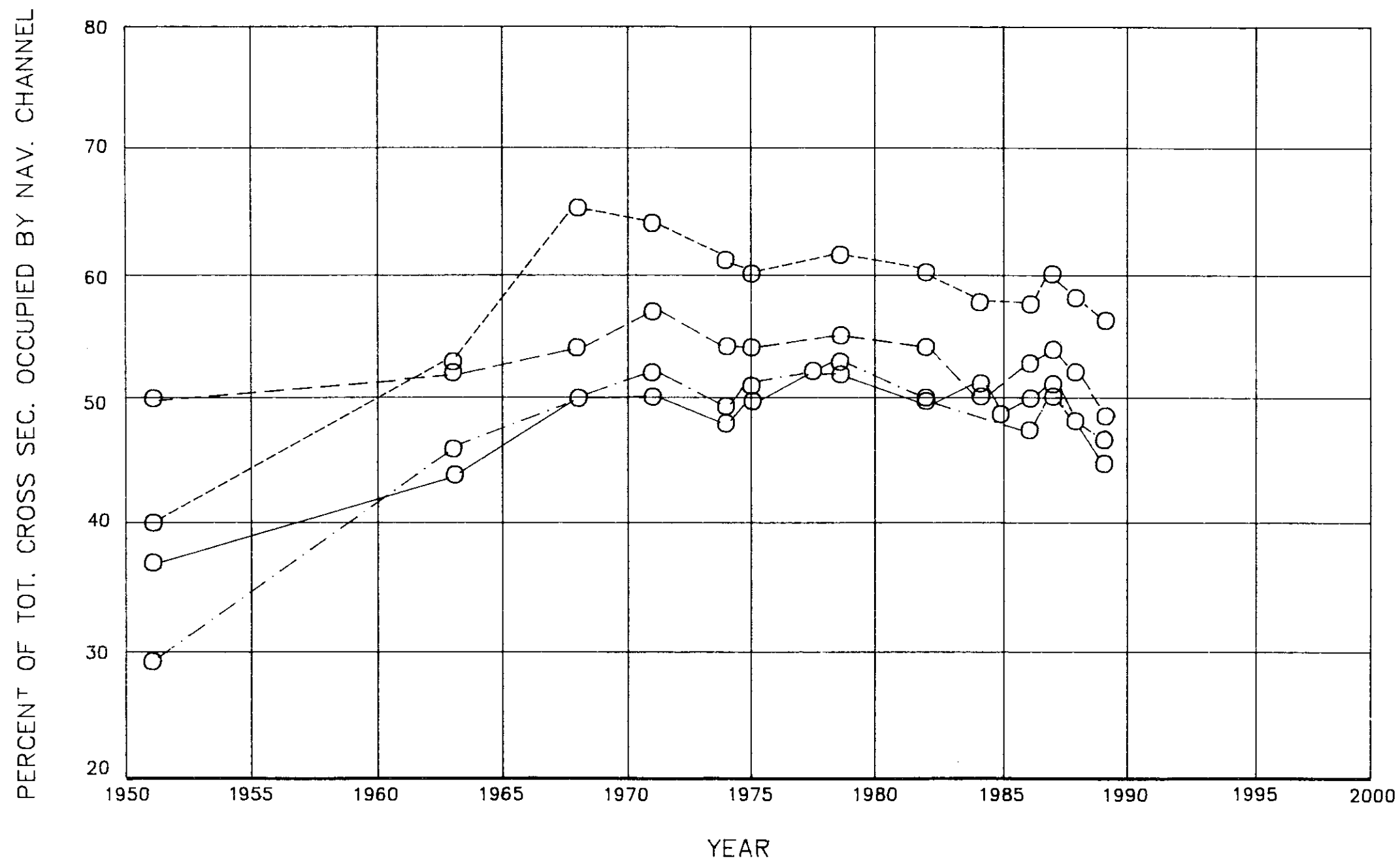
MISSOURI RIVER
GAVINS POINT DAM TO PLATSMOUTH, NE
DEGRADATION STUDY
SLOPE PROFILES, 1957, 1979, 1990
FIG. 13-S5





— TOTAL AREA
 - - - NAVIGATION CHANNEL AREA
 - - - AVERAGE WIDTH

FIG. 15-S5



RIVER MILE

———— 734-727

----- 720-715

----- 674-669

----- 617-612

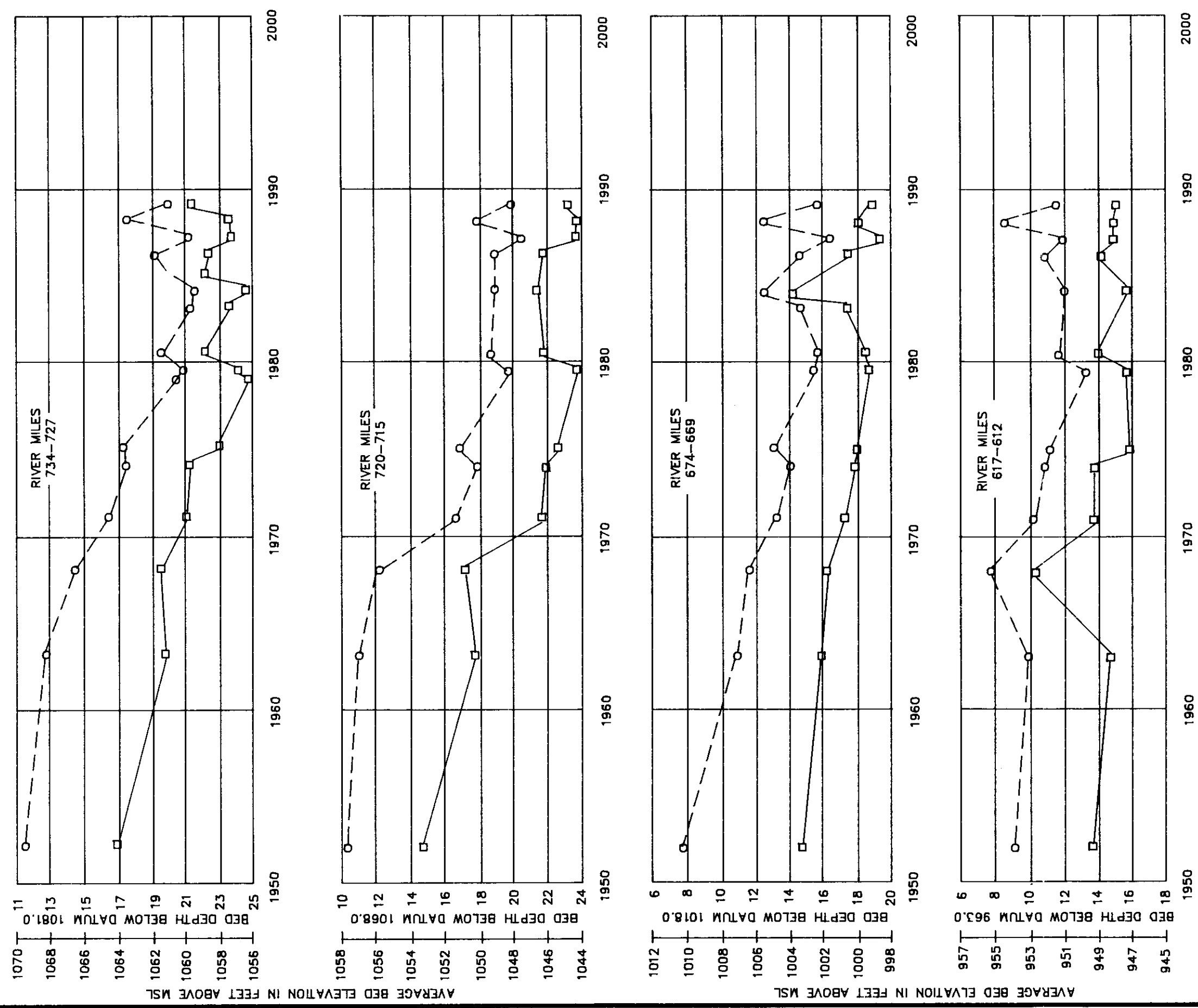
Prepared By Bp2

Reviewed By 12-1

MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY

PERCENT OF TOTAL CROSS SECTION OCCUPIED BY THE
NAVIGATION CHANNEL - SELECTED RIVER REACHES

FIG. 16-S5



○ --- AVERAGE BED ELEVATION OF TOTAL CHANNEL
□ --- AVERAGE BED ELEVATION OF NAVIGATIONAL CHANNEL

MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY

AVERAGE BED ELEVATION OF TOTAL CHANNEL AND AVERAGE
BED ELEVATION OF NAVIGATION CHANNEL - AREAS
WEIGHTED BY SUBREACHES - SELECTED RIVER REACHES

Prepared By *BAX*
Reviewed By -----

FIG. 17-S5

FIG. 17-S5

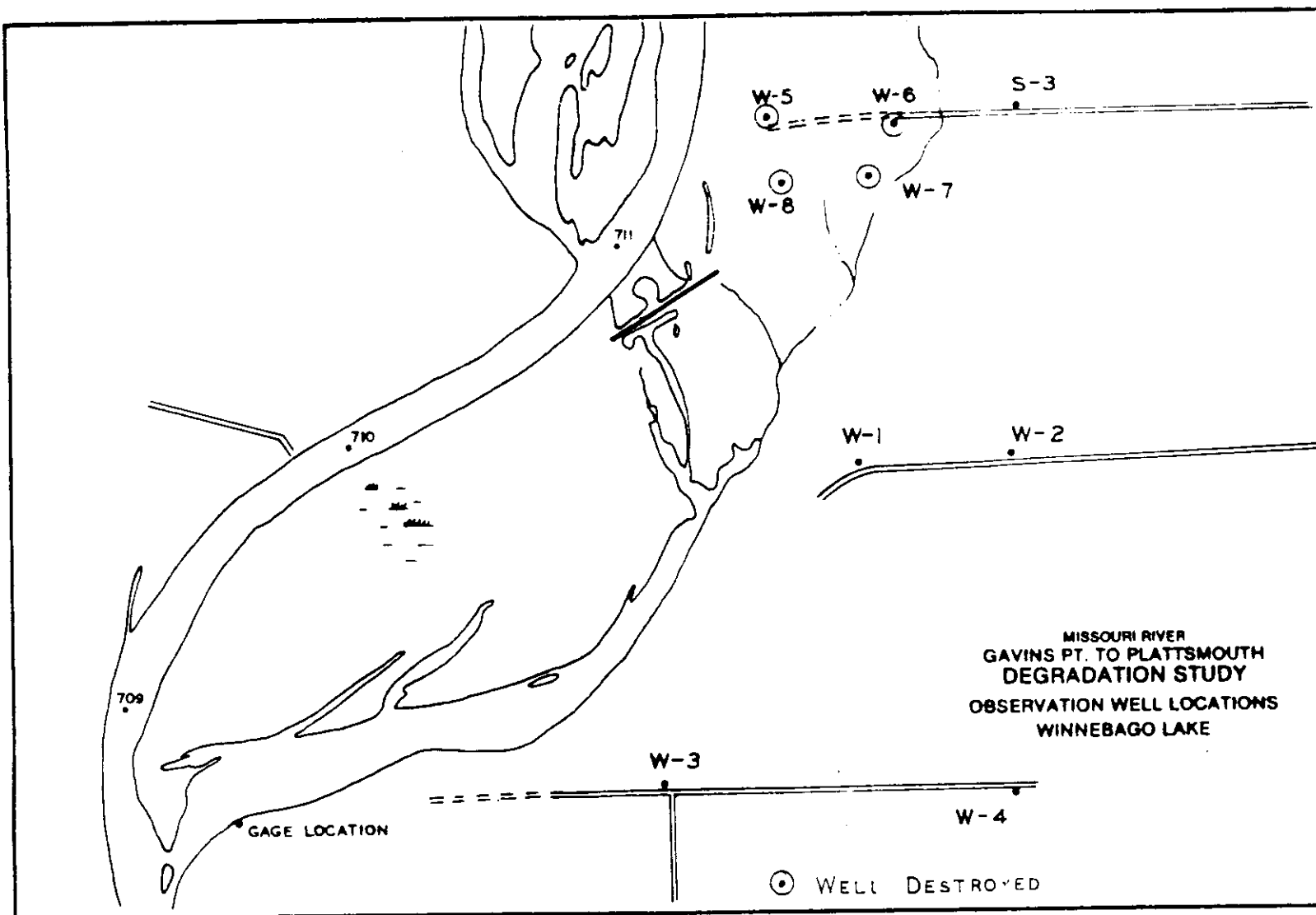


FIG. 18-S5

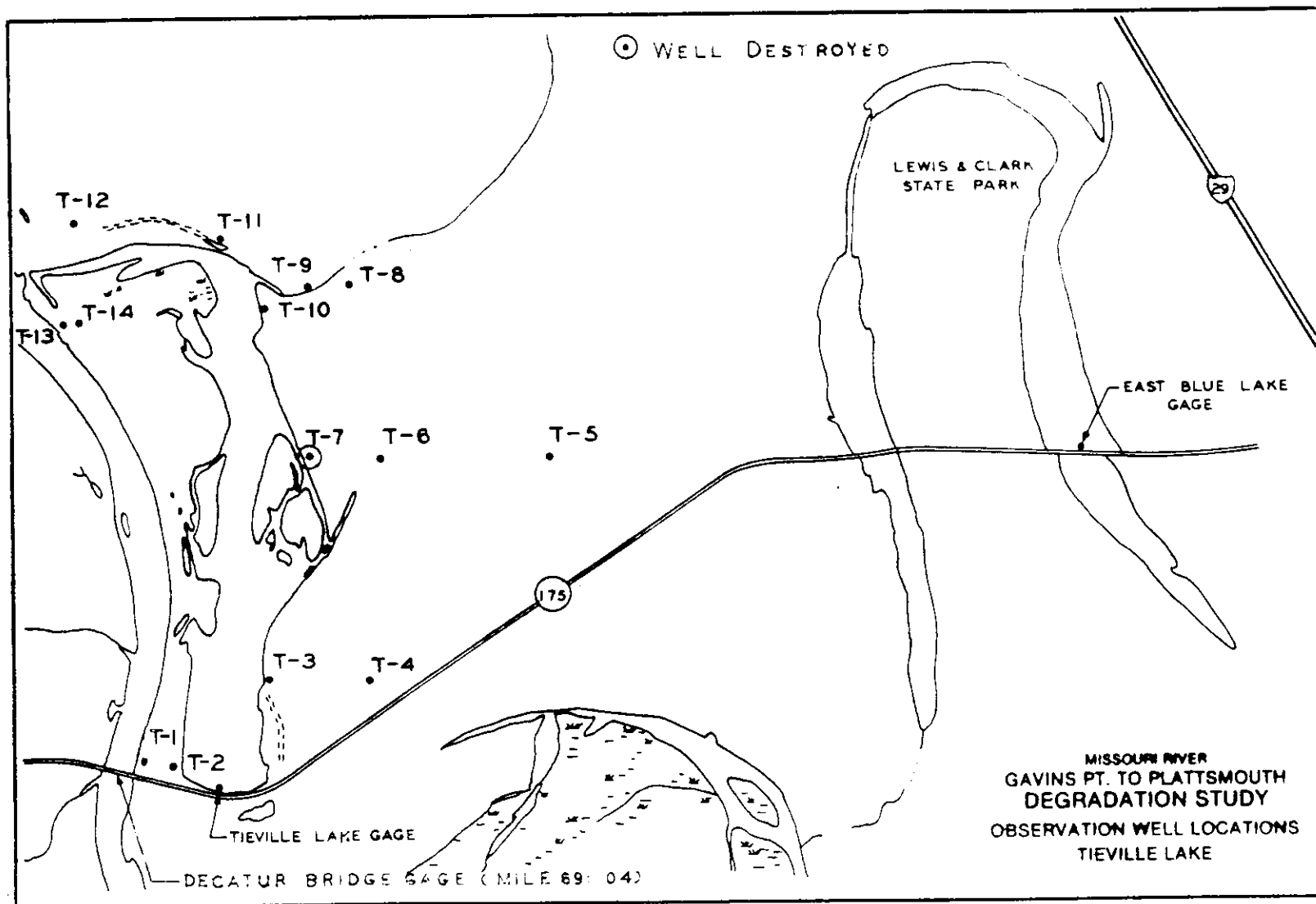
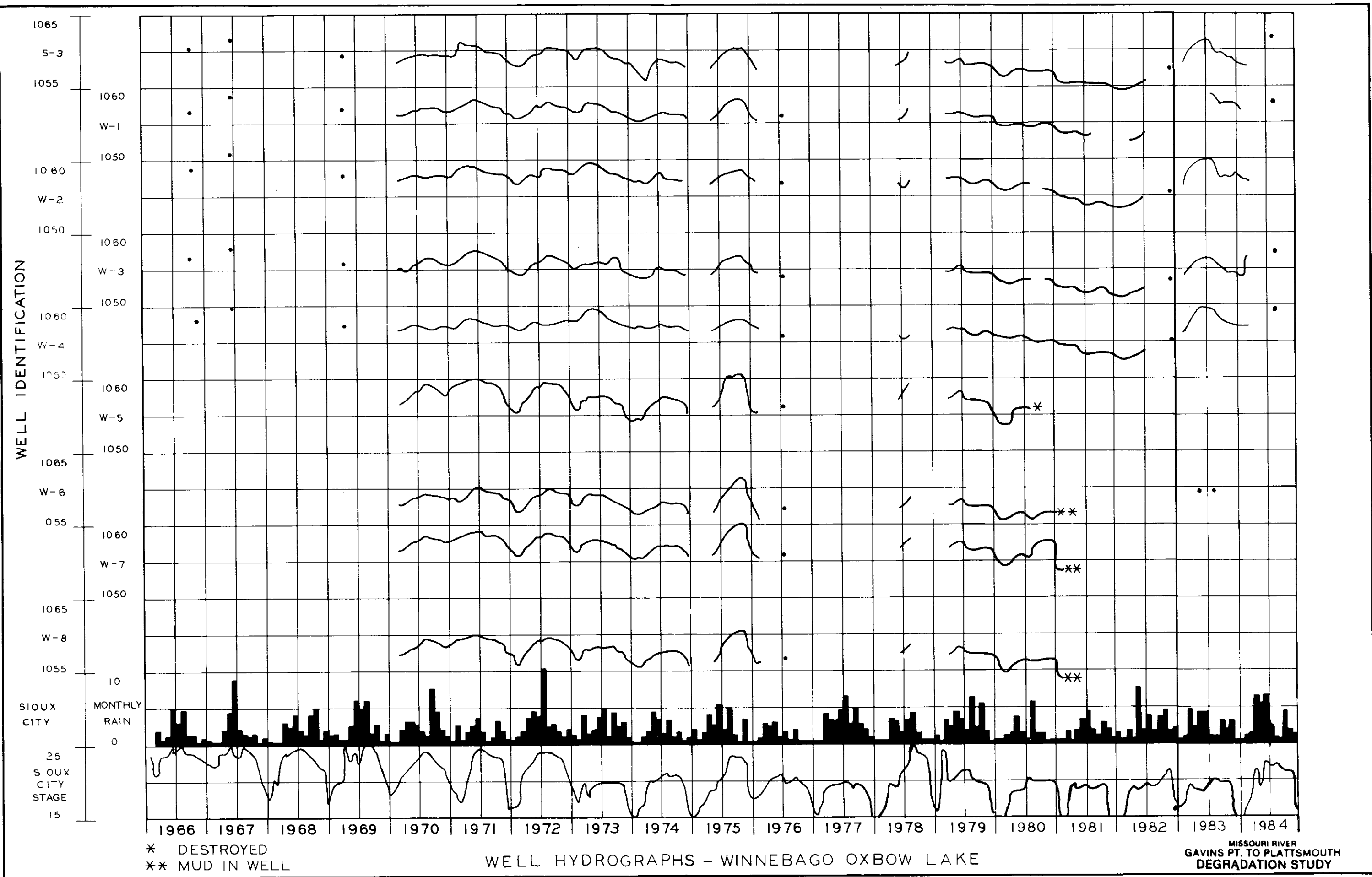
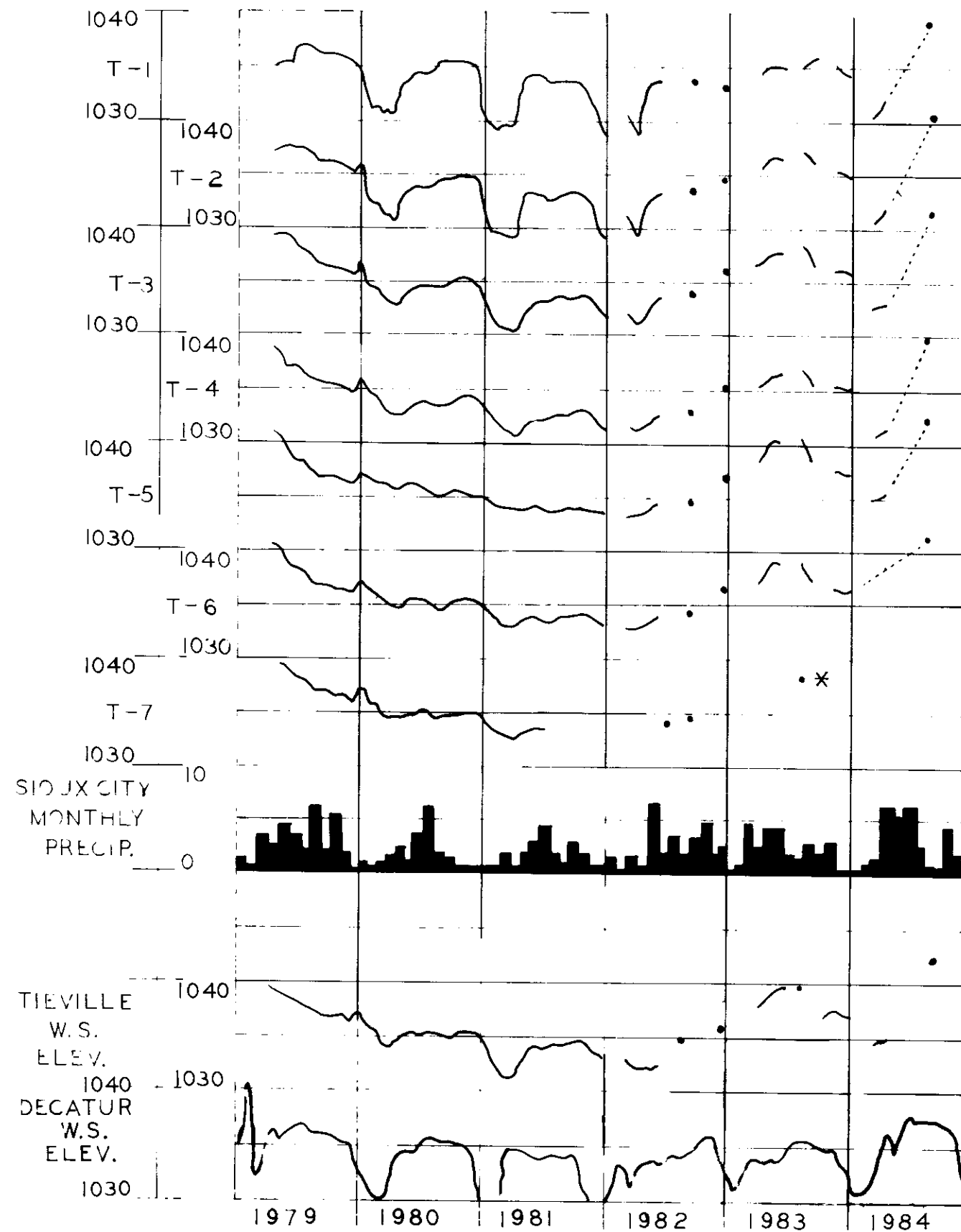


FIG. 19-S5



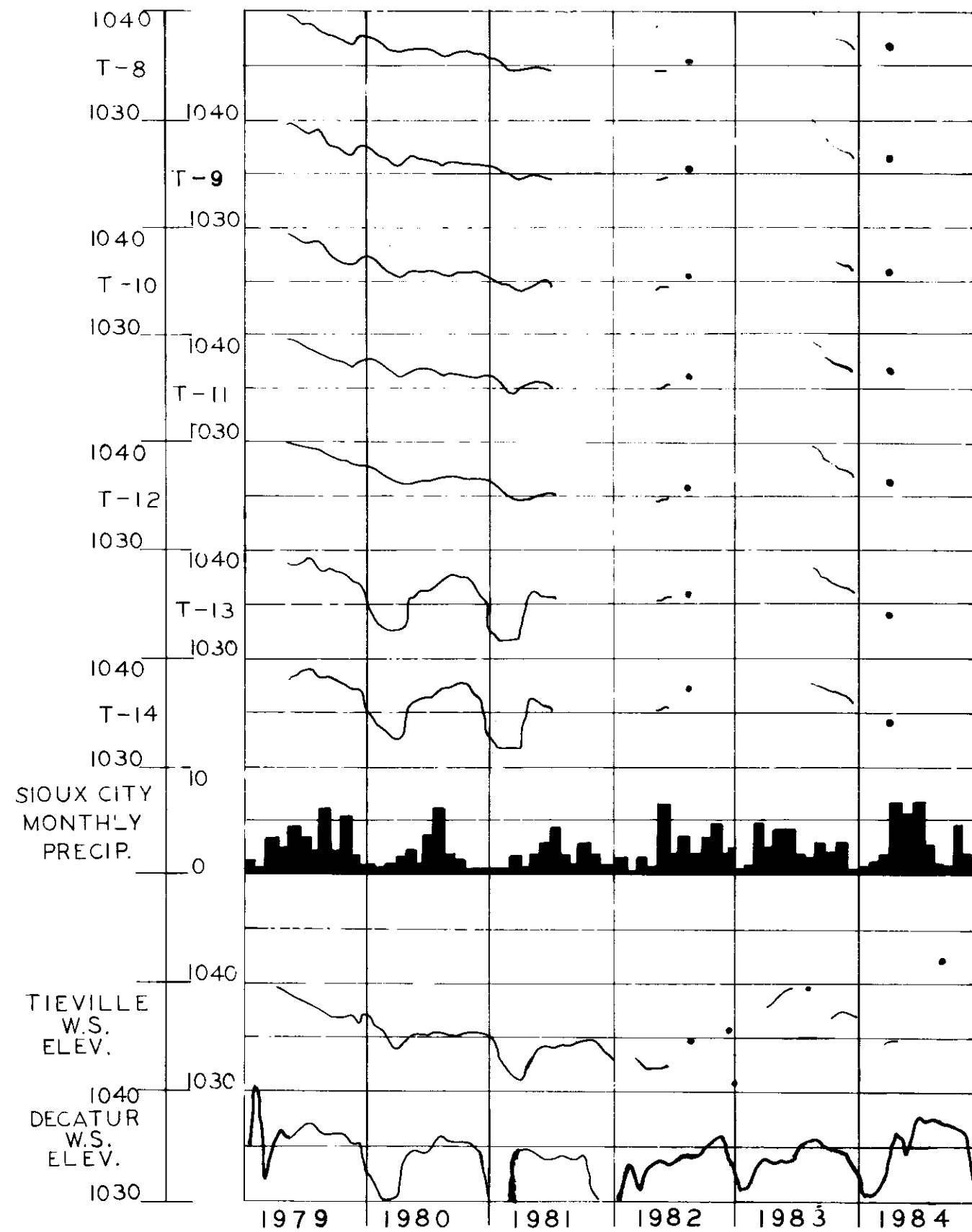
WELL IDENTIFICATION



* DEGRADED

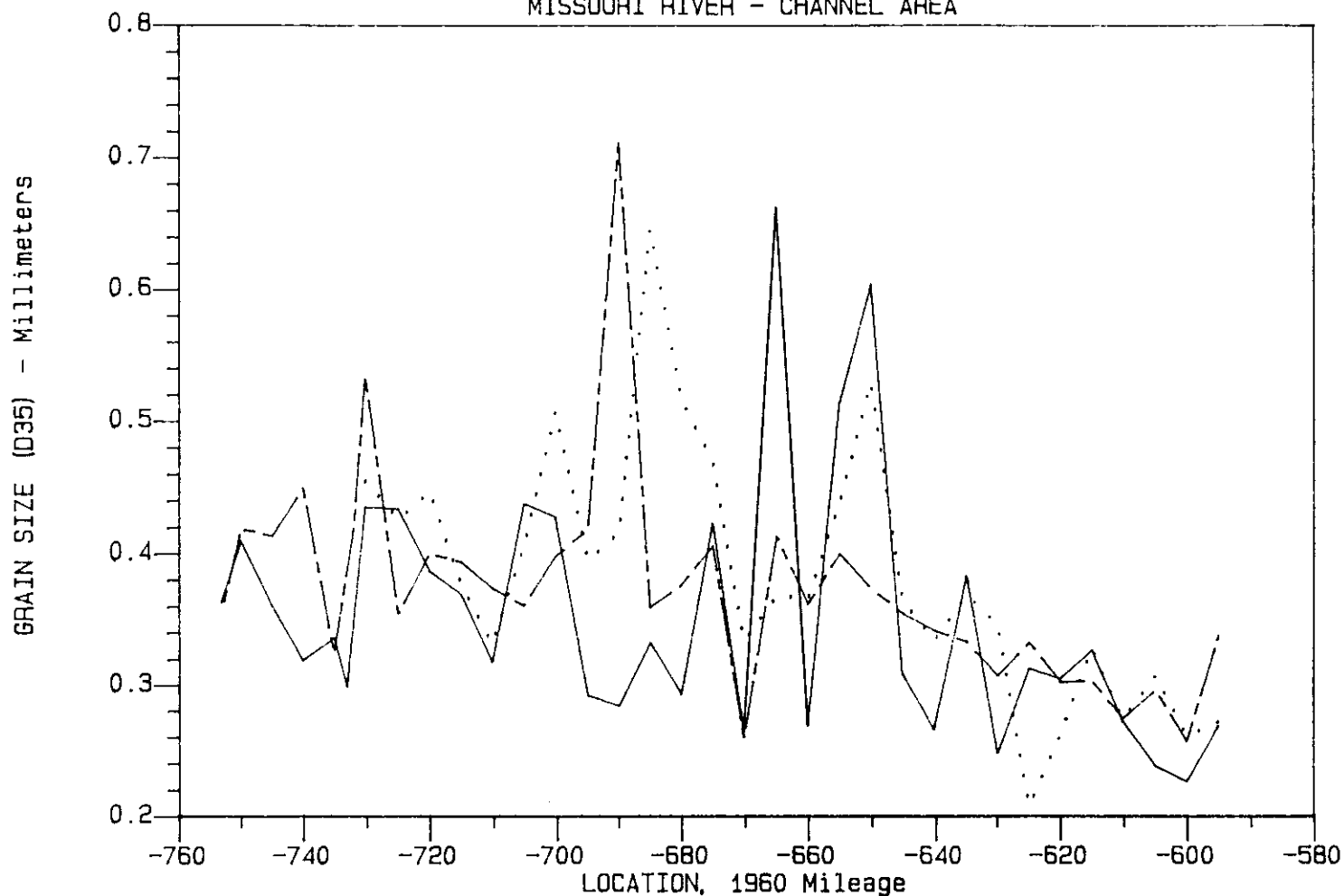
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
WELL HYDROGRAPHS (T1-T7) - TIEVILLE OXBOW LAKE
FIG. 21-S5

WELL IDENTIFICATION



MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
WELL HYDROGRAPHS (T8-T14) - TIEVILLE OXBOW LAKE
FIG. 22-S5

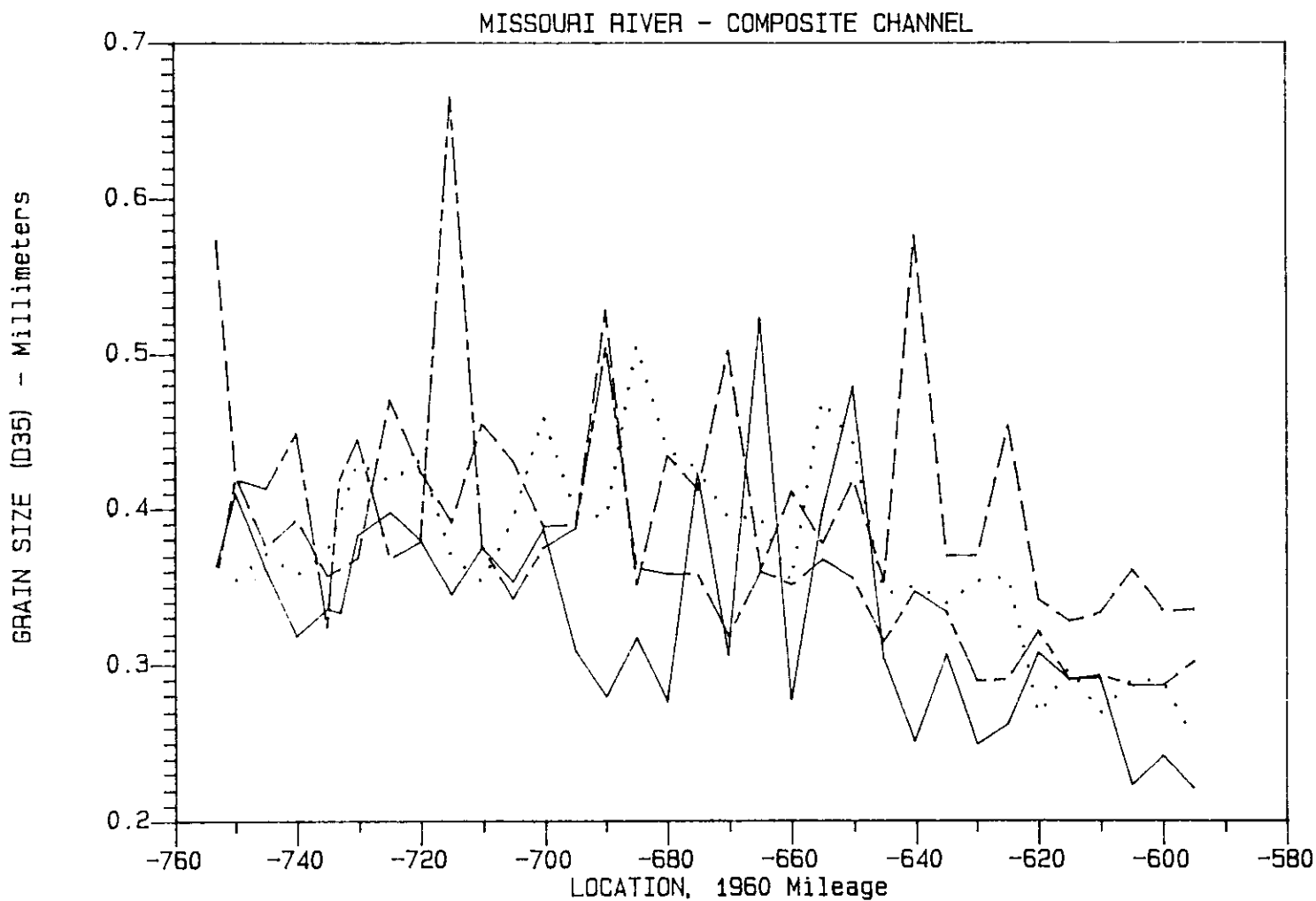
MISSOURI RIVER - CHANNEL AREA



MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY

BED GRAIN SIZE, D35 - CHANNEL AREA
FIG. 23-S5

Prepared By
Reviewed By



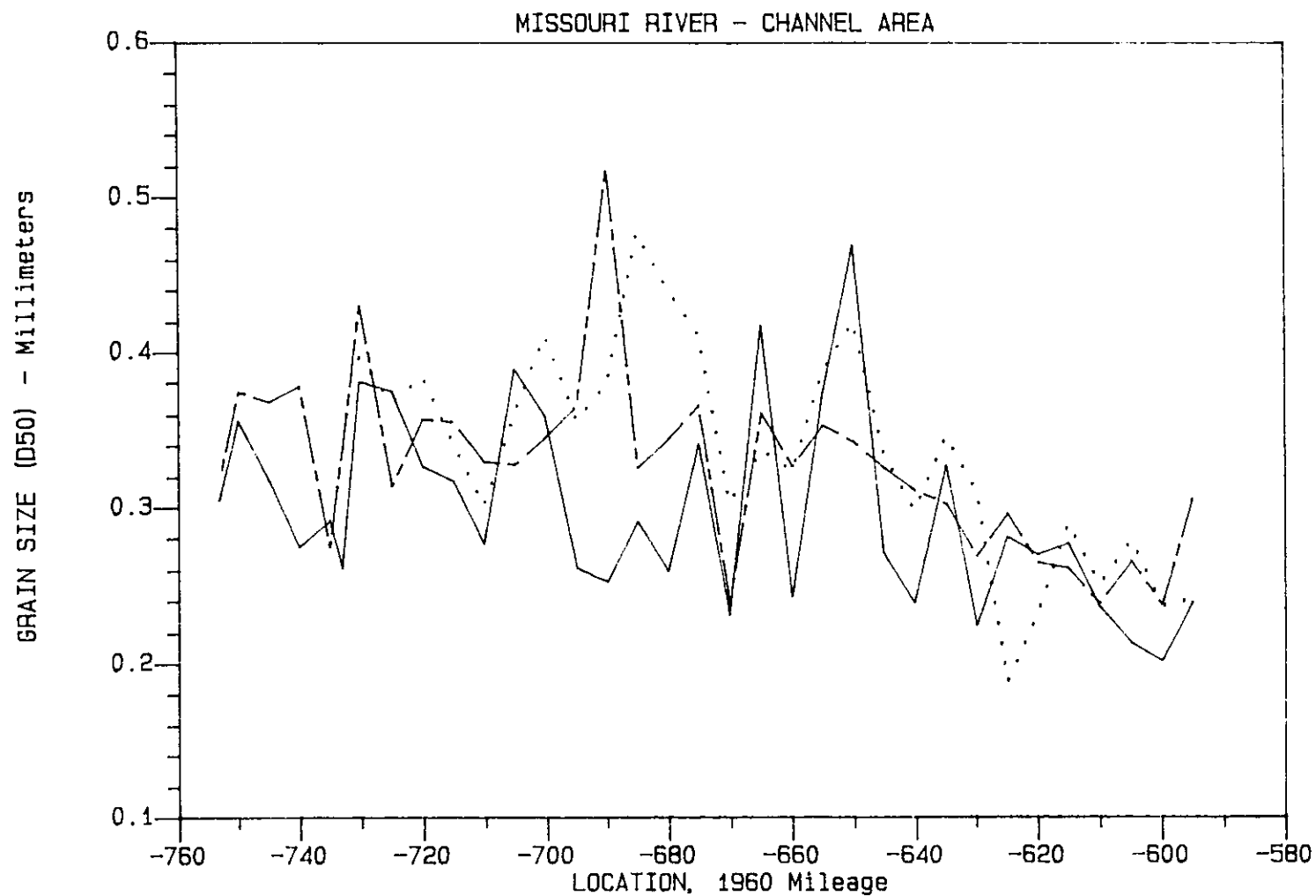
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE

DEGRADATION STUDY

BED GRAIN SIZE, D35 - COMPOSITE CHANNEL
FIG. 24-S5

Prepared By
Reviewed By

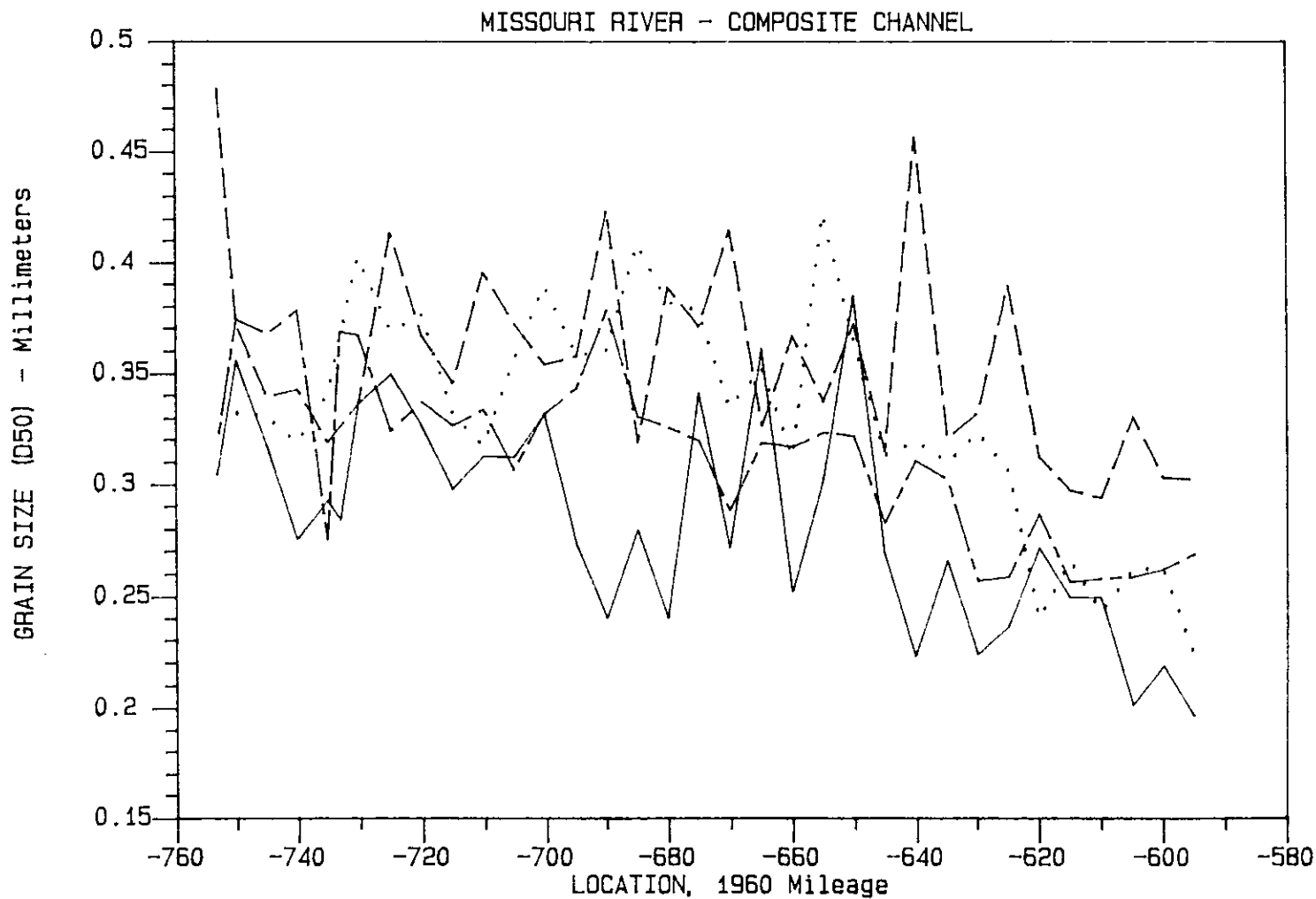
----- 25 SEP 1972
 - - - - - 04 SEP 1973
 23 OCT 1979
 - - - - - 31 OCT 1988



_____ 25 SEP 1972
 - - - - - 04 SEP 1973
 23 OCT 1979

Prepared By
 Reviewed By

MISSOURI RIVER
 GAVINS POINT DAM TO PLATTSMOUTH, NE
DEGRADATION STUDY
 BED GRAIN SIZE, D50 - CHANNEL AREA
 FIG. 25-S5



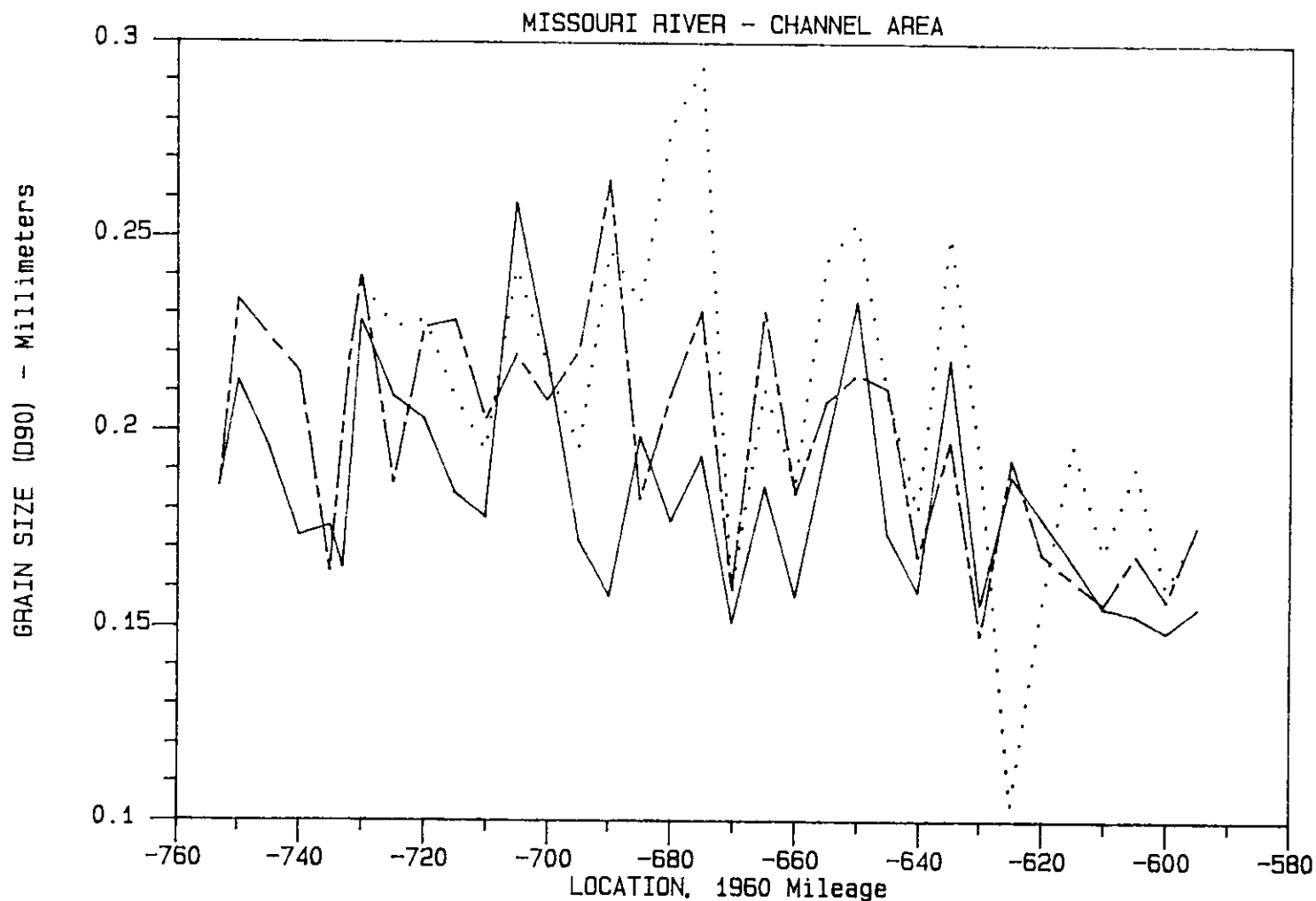
MISSOURI RIVER
GAVINS POINT DAM TO PLATTSMOUTH, NE

DEGRADATION STUDY

BED GRAIN SIZE, D50 - COMPOSITE CHANNEL
FIG. 26-S5

—————	25 SEP 1972
-----	04 SEP 1973
.....	23 OCT 1979
-----	31 OCT 1988

Prepared By JS
Reviewed By DK

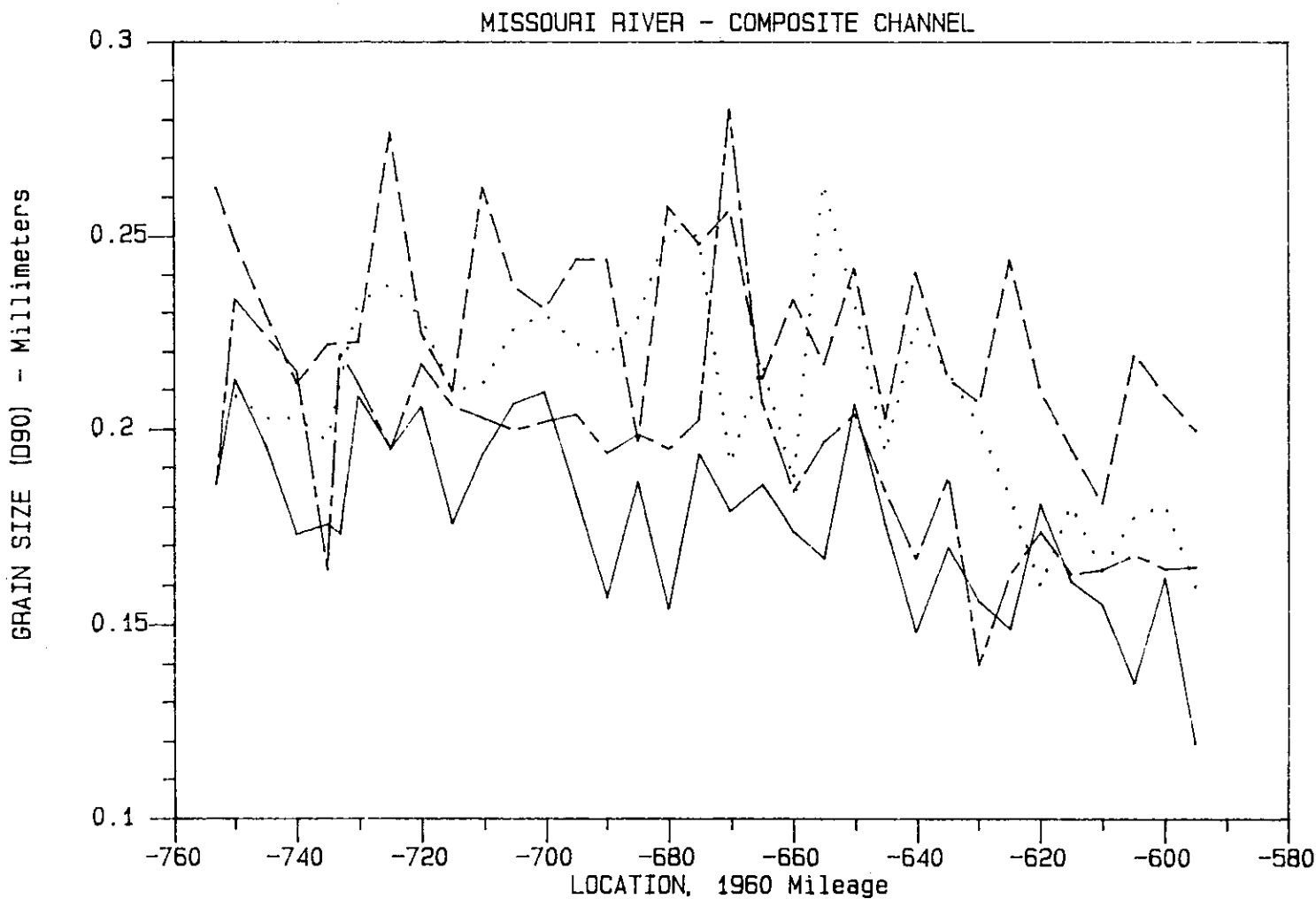


— 25 SEP 1972
 - - 04 SEP 1973
 . . . 23 OCT 1979

Prepared By
 Reviewed By

MISSOURI RIVER
 GAVINS POINT DAM TO PLATTSMOUTH, NE
 DEGRADATION STUDY

BED GRAIN SIZE, D90 - CHANNEL AREA
 FIG. 27-S5



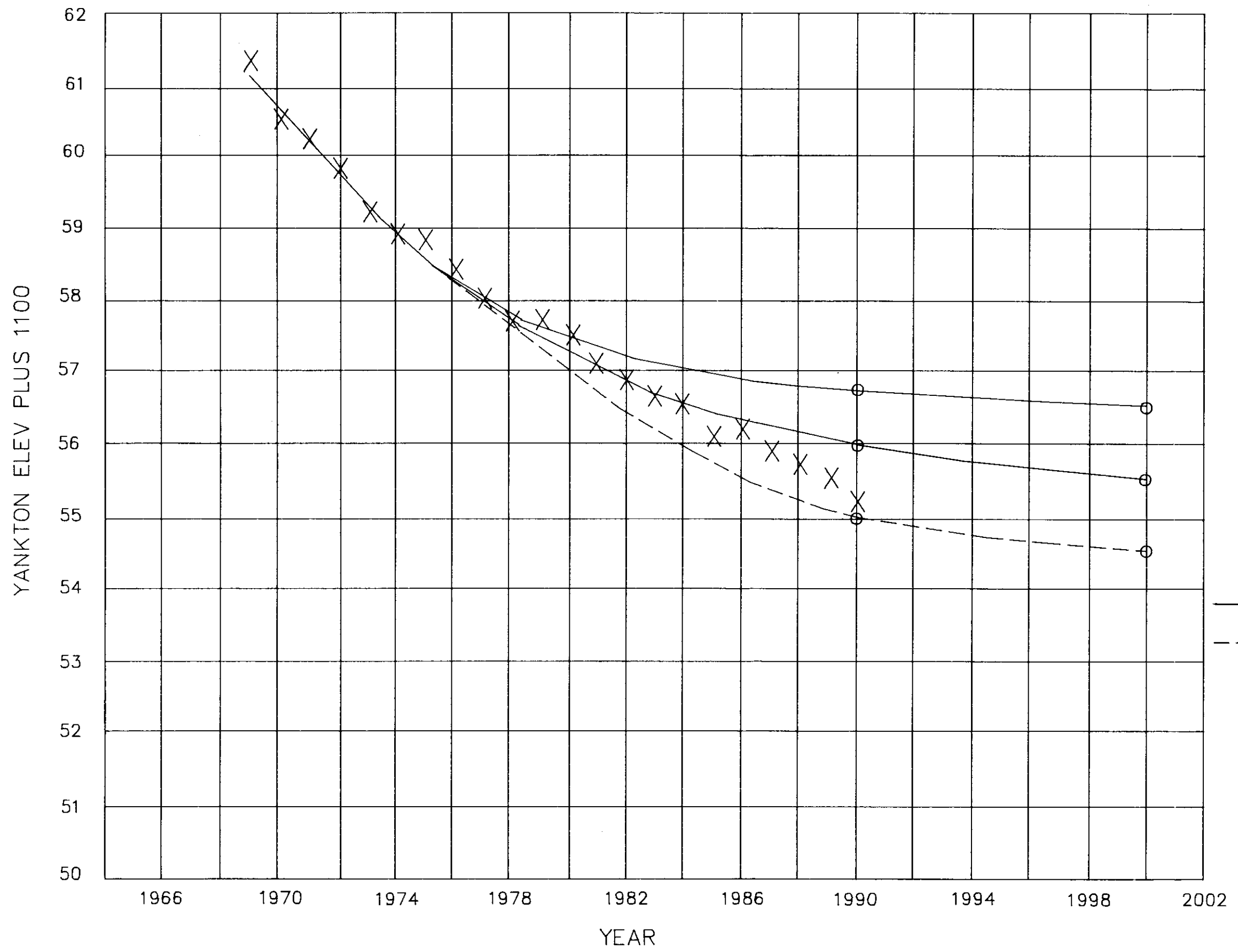
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DEGRADATION STUDY

BED GRAIN SIZE, D90 - COMPOSITE CHANNEL
FIG. 28-S5

Prepared By
Reviewed By

_____ 25 SEP 1972
 - - - - - 04 SEP 1973
 23 OCT 1979
 - . - . - 31 OCT 1988



LEGEND

— Original Projection, Upper and Lower Range

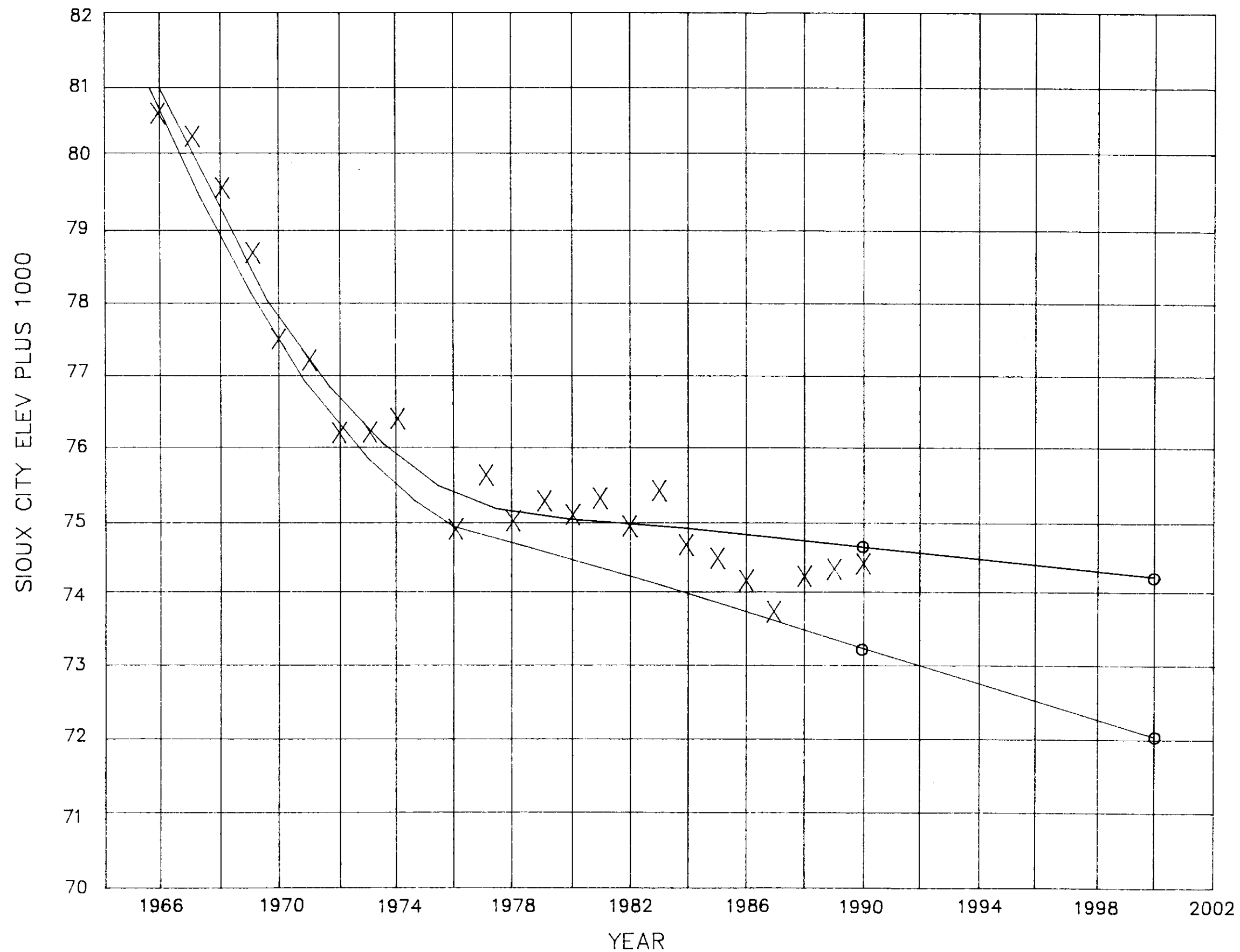
- - - Modified Projection, Reflecting Post-1986 Data

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YANKTON SHORT RANGE DEGRADATION PROJECTIONS

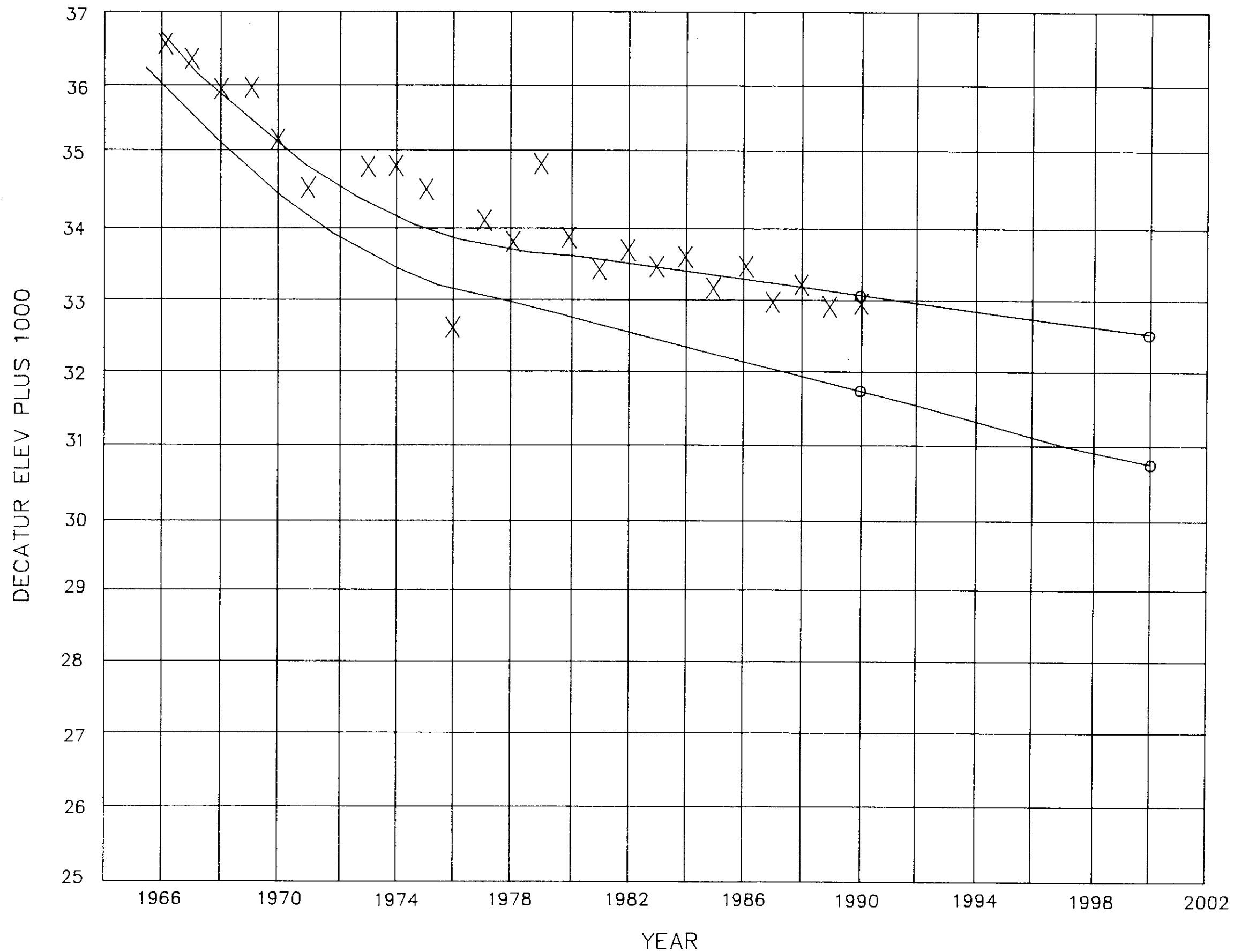
FIG. 29-S5



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 DEGRADATION STUDY
 SIOUX CITY SHORT RANGE DEGRADATION PROJECTIONS

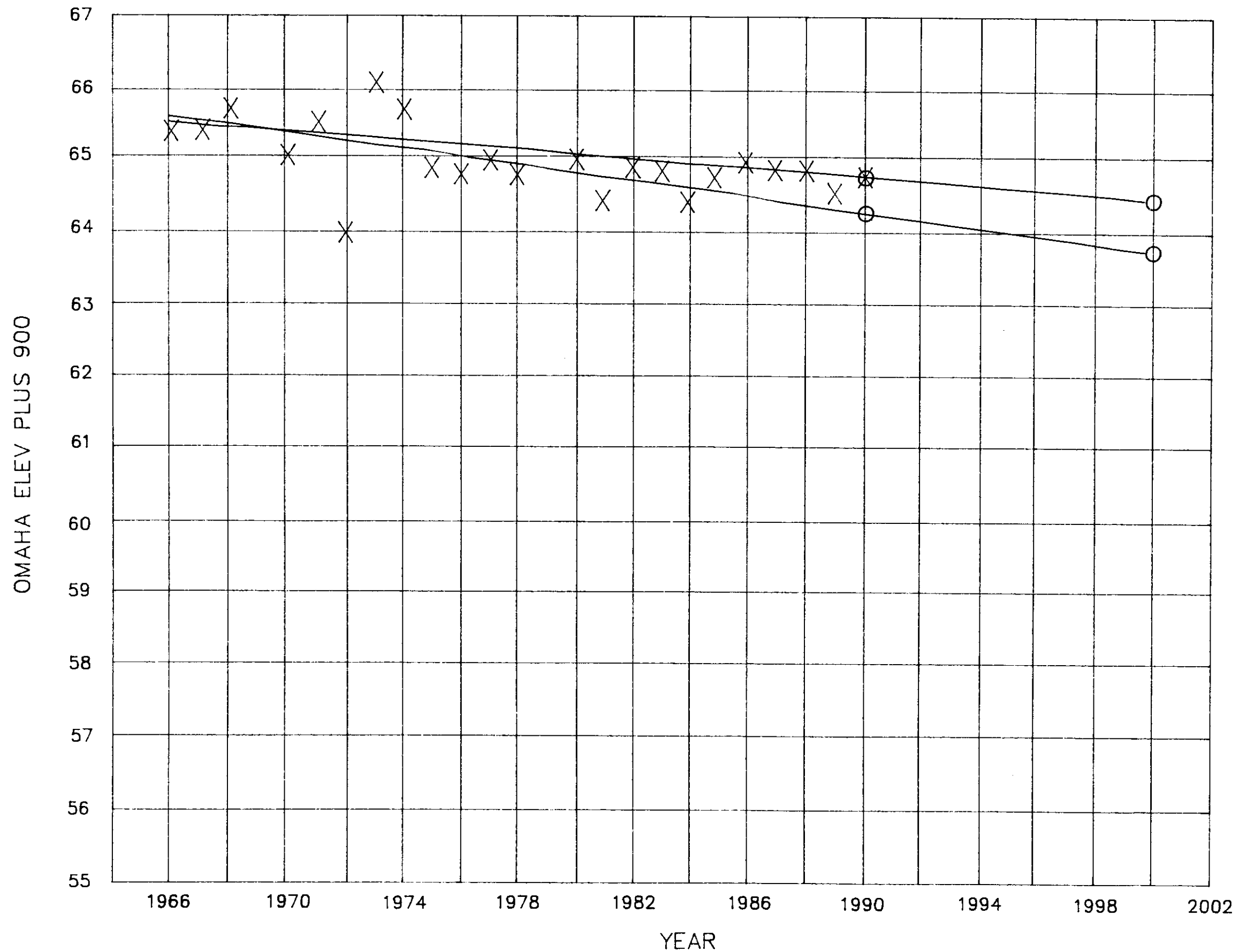
FIG. 30-S5



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DEGRADATION STUDY
DECATUR SHORT RANGE DEGRADATION PROJECTIONS

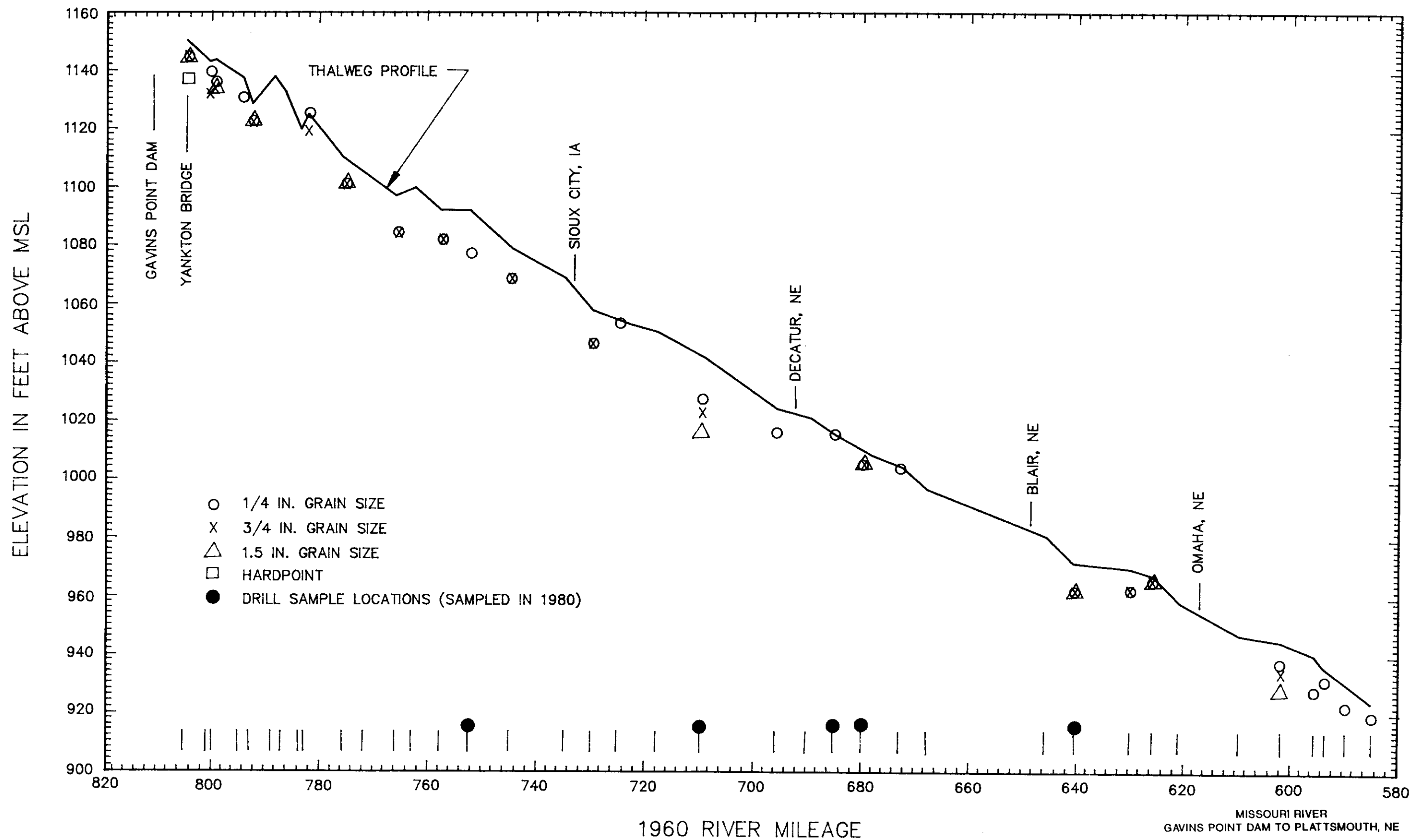
FIG. 31-S5



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DEGRADATION STUDY
 OMAHA SHORT RANGE DEGRADATION PROJECTIONS

FIG. 32-S5



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 Reviewed By DK

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 DEGRADATION STUDY
 1978 CORE DRILL SAMPLES - UPPER LEVELS OF COARSE
 GRAVELS AND ROCK OUTCROPPINGS

FIG. 33-S5